Vol. LXXXVII. No. 6. November–December, 1950

GEOLOGICAL MAGAZINE

Edited by

O. M. B. BULMAN and S. R. NOCKOLDS

assisted by

PROFESSOR W. S. BOULTON
PROFESSOR W. G. FEARNSIDES
PROFESSOR LEONARD HAWKES
PROFESSOR O. T. JONES
PROFESSOR W. J. PUGH
PROFESSOR C. E. TILLEY
HENRY WOODS

CONTENTS

	PAGE
TROMP, S. W. The Age and Origin of the Red Sea Graben	385
SPENCER, W. K. Asterozoa and the Study of Palaeozoic Faunas	393
MACFADYEN, W. A. Sandy Gypsum Crystals from Berbera, British Somaliland	409
PART, G. M. Occurrence of Nepheline-Monzonite and Allied Types in the Cape Verde Archipelago	421
MCINTYRE, D. B. Note on Lineation, Boudinage, and Recumbent-folds in the Struan Flags (Moine), near Dalnacardoch, Perthshire	427
KOLBUSZEWSKI, J., NADOLSKI, L., and DYDACKI, Z. Porosity of Wind-Deposited Sands	433
PRENTICE, J. E. The Genus *Gigantella* Sarycheva	436

CORRESPONDENCE

Carboniferous Reef Limestones. W. W. BLACK	438
New "Species". T. G. MILLER	439
Supposed Fossil from the Charnian. G. M. FRIEDMAN	441
Zoological Nomenclature: Article 25. F. HEMMING	442
Depth of Burial of S. Wales Coals. F. M. TROTTER	444

REVIEWS
pages 445–6

INDEX
pages 447–50

STEPHEN AUSTIN & SONS, LTD.
1 FORE STREET, HERTFORD, HERTS

SUBSCRIPTION 30/- PER ANNUM

GEOLOGICAL MAGAZINE

founded in 1864

by the late Dr. H. Woodward, F.R.S., with which

is incorporated

THE GEOLOGIST

(founded 1858)

Published every two months, price 30/- per annum
(single numbers, 7/6).

Subscriptions for 1950, inquiries relating to back stock, advertising, etc., should be sent to Stephen Austin & Sons, Ltd., Fore Street, Hertford, Herts.

Instructions to Contributors.

Articles submitted for publication in the *Geological Magazine* should be addressed to the Editors at the *Sedgwick Museum, Cambridge*, not to the Publishers.

Manuscripts should be typewritten, double-spaced, and preferably with a wide margin, and should be carefully revised ; they should be as concise as possible, and in no case should an article exceed 10,000 words. MS. must be accompanied by a short abstract, 50–100 words. References should not be given in footnotes, but arranged in alphabetic order of author's names at the end of the article ; the author's name should be followed by date of publication, and the title of each paper should be given in addition to volume and page numbers of the Journal, thus :—

LAPWORTH, C. 1878. The Moffat Series. *Quart. Journ. Geol. Soc.*, xxxiv, 240–343.

References should be cited in the text by author's name and date, with page reference if necessary, in brackets :—(Lapworth, 1878, p. 339).

Illustrations should be so drawn as to allow reduction to a maximum size of $6\frac{1}{4} \times 3\frac{1}{2}$ inches (the type-area of the Magazine) and originals must not exceed 40×22 inches. Map lettering should be such as to be clearly legible after reduction (equivalent to 5-point as a *minimum* on reduction), while lettering on text-figures should in general be left in pencil for printing.

Authors will receive 25 reprints free of cost.

GEOLOGICAL MAGAZINE

VOL. LXXXVII. No. 6. NOVEMBER–DECEMBER, 1950

The Age and Origin of the Red Sea Graben

By S. W. TROMP

ABSTRACT

A brief summary is given of the origin and geological history of the Red Sea Graben area, based on personal observations in Egypt during the periods 1937–1940 and 1947–9. The author is inclined to believe that the graben zone was formed in its initial stages at the end of the L. Eocene ; the movements continued at least till Pleistocene times. The mechanism of the graben is explained as a combination of regional shearing faults together with regional updoming followed by stretch-faulting.

I. INTRODUCTION

DURING the last fifty years a great number of publications appeared on the origin of the Red Sea Graben zone and its continuation towards East Africa and Turkey (Krenkel, 1922). A careful study of these publications indicates, however, that only very few were based on actual field observations and of these the observations were only made during short reconnaissance trips. If all geophysical and geological surface and sub-surface data known at present to the main oil exploration companies of Egypt (Royal Dutch Shell, Standard Oil Co. of Eygpt, and Socony Vacuum Oil Co.) could be published, no doubt a very accurate history of the greatest part of the Gulf of Suez could be written. However, as this is an Utopia it was considered to be useful to publish at least a few permissible data on this classical area.

II. AGE OF THE GRABEN ZONE

We mentioned already (Tromp, 1949 and 1950) that the Gulf of Suez Graben was formed initially at the end of the L. Eocene, but the fault movements continued at least till Pleistocene times. Some of the arguments favouring this statement are the following :—

(1) The Gulf of Suez, with a N.W.–S.E. direction, cuts almost perpendicularly the N.E.–S.W. folding trends of N. Sinai (Tromp, 1949). The differences in facies between flank and centre of some of these Sinai structures (e.g. Gebel Maghara), in the Cenomanian and

Turonian beds indicates that these folding lines probably existed already in Cretaceous times (Tromp, 1950). The Wadi Araba structure on the west coast of the Gulf of Suez (see map) indicates that the direction of the Gulf of Suez is the youngest one and has cut the Cretaceous direction.

(2) Up to the basal M. Eocene there is little difference in facies between both sides of the Gulf of Suez.

(3) The important regional unconformity at the base of the M. Eocene in most areas between Egypt and Turkey, causing the direct deposition of M. Eocene limestones on basal Eocene or even Cretaceous beds (Tromp, 1950), indicates major tectonic movements in this part of the world at the close of the L. Eocene.

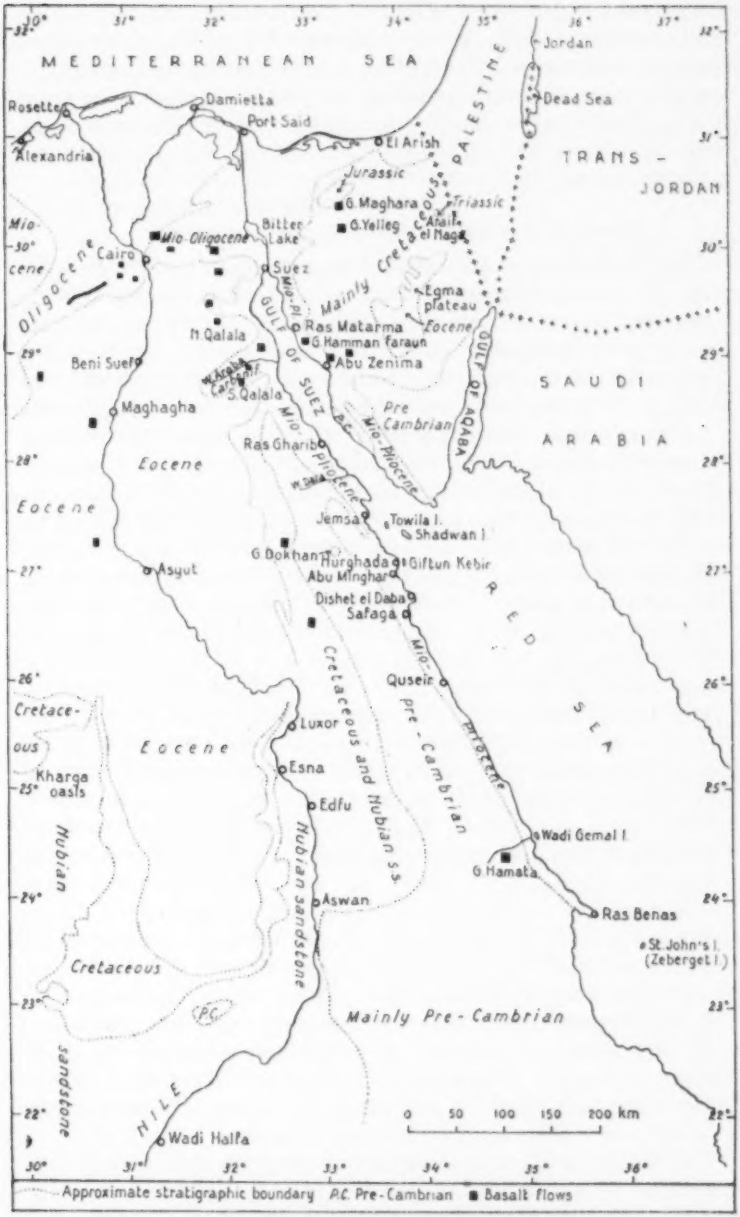
(4) There is a large erosional hiatus at the base of the Miocene in the Gulf of Suez indicating strong tectonic movements followed by a long period of erosion in pre-Miocene time (Tromp, 1949 and 1950).

All these different facts indicate that the Red Sea Graben originated in pre-Miocene and most probably in basal M. Eocene time. This graben did not subside, however, as one block during the Neogene, but differential block-movements took place.

(5) In Wadi Dara (west side of Gulf of Suez), in a deep oil well drilled by the Socony Vacuum Oil Co., a continuous section was encountered containing Pliocene, the whole Miocene, Oligocene, and U. Eocene (well was abandoned at this stratigraphic level). Both Oligocene and U. Eocene are developed as a marine facies, their ages being established by micro-faunal analysis (Tromp, 1950). The presence of marine Oligocene and U. Eocene in the deeper parts of the Gulf of Suez Graben, whereas this section is missing in the region directly west of the Graben fault (M. Eocene being present in those areas) indicates that this depression was formed in pre-U. Eocene and probably in M. Eocene times. Also the presence of basal Eocene in sub-surface sections (e.g. west of Ras Gharib) both in the graben itself and outside of it, and of M. Eocene (unconformably overlying Cretaceous beds at the edge of the Graben fault) indicates a basal M. Eocene age for the first large structural movements in this area.

During the Miocene transgression the deepest parts of the graben were covered first but some of the higher eroded peaks of the graben blocks were covered for the first time only in U. Miocene times. These overlap conditions, which can be seen on the surface (e.g. in Gebel Zeit) and in subsurface sections of the different oil structures in the Gulf of Suez area, are another clear indication that the graben structures existed in pre-Miocene times.

Although the first definite subsidence and block-faulting in the Gulf of Suez must have taken place in the basal M. Eocene, it seems probable that the Red Sea Graben zone may have existed as a zone of



TEXT-FIG. 1.—Locality map of Egypt and the Red Sea.
(Partly copied from Ball.)

weakness in much older periods. Facies researches on hand suggest that facies boundaries in the Cretaceous deviate considerably from the east–west direction which may be due to a pre-existing topography. Also the regional extension of these different graben zones in this part of the world suggests an older age. It should be kept in mind, however, that no positive evidence is available for this assumption, at least not in Egyptian territory.

III. Structural History of the Graben Zone

The actual history of the Gulf of Suez area is less simple than may appear from the above-mentioned facts. We mentioned previously (Tromp, 1950) that from 25° N. latitude to the Mediterranean the whole of Egypt subsided during the Mesozoic and L. Eocene. The subsidence started in the north and took place with greater speed than in the south. As a result during the Jurassic continental deposits (Nubian sandstones) were formed in S. Egypt, whereas at the same time marine sediments were deposited further north. In the U. Senonian practically the whole of Egypt, at least as far south as 25° latitude, was covered by the sea. At the end of the L. Eocene reversed movements took place. A regional updoming occurred, accompanied by considerable block-faulting along old (probably pre-Cretaceous) fault-zones (Tromp, 1949) with, at least partly, N.E.–S.W. direction. These block-movements created large dome-shaped structures, such as G. Maghara and G. Yelleg in N.E. Sinai, Abu Roash, west of Cairo, etc. Erosion removed the L. Eocene and uppermost Cretaceous in the high uplifted parts, and as a result during the following period of regional subsidence M. Eocene limestones were deposited on older beds with a considerable hiatus. In the deeper, less upfolded, parts of Egypt sedimentation continued and as a result no hiatus exists or only a very small one. The M. Eocene transgression was followed by a second period of regional updoming (probably more important even than the previous one) which was accompanied by local cross undulations. From this period onwards great parts of S. Egypt stayed more or less permanently above sea-level. Only north of latitude 28° subsidence continued during the U. Eocene, the sediments being deposited on a tectonically undulated surface. In the Gulf of Suez graben faults brought the M. Eocene far below sea-level again ; this is indicated, for example, in the subsurface-sections of the oil structure near Ras Matarma (east side of the Gulf of Suez), where a thick Miocene section is overlapping M. Eocene limestones which form the crest of the eroded pre-Miocene blocks.

Several of the blocks that subsided in the Gulf of Suez depression remained above sea-level or moved temporarily upwards as a result of local antithetic block movements (Cloos, 1928 and 1932). Erosion

removed the Tertiary and older beds from the crest of those blocks, often as far down as the pre-Cambrian granites. Further subsidence during Oligocene times enabled Miocene beds to cover directly these granite peaks. Whereas in the Red Sea graben zone subsidence continued throughout the Miocene, Pliocene, and Pleistocene only temporarily interrupted by local uplifts as a result of tilted block-movements in the graben, Egypt as a whole was rising continuously ; this is indicated by different facts :—

(1) The fluvio-marine facies of the U. Eocene was gradually moving northwards during the Miocene and younger periods (Tromp, 1950) ; in other words, the continental conditions prevailing in U. Eocene times south of latitude 28° N. gradually appeared further north and large rivers from the south filled up the basins north of Fayum.

(2) Thick marine Pleistocene beds were encountered in sub-surface sections along the Gulf of Suez, whereas at the edge of the Graben Pleistocene and older uplifted terraces can be found.

(3) The sudden change in facies of the Pliocene (sandstones, grits, boulder deposits, etc.), after the deposition of about 120 m. of solid anhydrite, gypsum, or rock-salt during the U. Miocene, as a result of the closure of the Gulf of Suez and Red Sea both in the north and south (Tromp, 1950), indicates a reopening of this basin, probably accompanied by vertical uplifts of the bordering areas followed by a sudden increased erosional activity.

IV. Mechanism of the Red Sea Graben Faults

Three outstanding phenomena must be taken into consideration in any theory on the origin of the Red Sea Graben zone :—

(1) Sinai, N. Egypt, and the Gulf of Suez formed one large updoming area, the movements of which started at the end of the L. Eocene, but became very large at the end of the M. Eocene. After this period the rising movements continued more or less regularly throughout the whole Tertiary.

(2) Since the M. Eocene a N.W.–S.E. zone crosses this updoming area, the so-called Red Sea Graben zone, which subsided more or less continuously during the whole Tertiary and Pleistocene.

(3) Large basalt extrusions took place at different places in Egypt (see map), the age of which in several cases could be established to be definitely U. Oligocene and pre-L. Miocene.

(*a*) In the Cairo–Suez area a fluvio-marine Oligocene section outcrops which is more than 40 m. thick ; this covers unconformably a definitely U. Eocene section. At the top of the Oligocene sandstones, etc., a thick basalt flow occurs (up to 18 m.). These basalt flows are unconformably covered by definitely L. Miocene marine deposits. No traces of volcanic activity are found in the L. Miocene. In other

words, these basalt flows represent a relatively short, well-marked period of volcanic activity.

(*b*) The same conditions can be found north and north-west of Fayum indicating a similar U. Oligocene age.

(*c*) Also the basalt extrusions on the west side of the Gulf of Suez, north of the North Qalala Plateau, about 45 km. west of Bir Odeib, indicate the same field relations as in the Cairo–Suez area.

(*d*) Near Hammam Faraun (east side of the Gulf of Suez) and further south near Abu Zenima an interesting surface section is exposed near the edge of the graben faults. The Upper Eocene Tanka beds (Tromp, 1950) are covered unconformably by a basal conglomerate which is overlain by 40 m. of reddish sandy marls, calcareous sandstones, and sandy limestones, which in their turn are covered by a conglomerate which is overlain by a thick (up to 40 m.) dolerite bed. This dolerite bed is usually covered again by a conglomerate which is overlain by sandy Lower Miocene marine deposits. In other words, a condition similar to the Cairo–Suez region. Near Hammam Faraun, in the neighbourhood of the edge faults of the graben, a hot-water spring occurs.

(*e*) In Ras Lagia, north of Hamman Faraun, the Socony Vacuum Oil Co. encountered in an oil-exploration well between 2,300 and 2,500 feet the same dolerite sill which further south is outcropping on top of the U. Eocene.

There is no reason to assume that the other basalt outcrops in Egypt are different in age. Some are definitely post-Upper Eocene, others post-M. Eocene, but lack of marine Miocene deposits prevents us from dating them more accurately.

If we consider these different facts there seems to be little doubt that the formation of the Gulf of Suez was preceded by a regional updoming. This regional fold was due either to a regional *buckling phenomenon* (Tromp, 1937, pp. 8–18, and 1949) as a result of two opposing, mainly north–south directed geotectonic forces in the African continent or to the *Helmholtz mechanism* (Tromp, 1937 and 1941), in other words, to "*frictional undulation*" created by the movements of the sial crust with respect to the sima. In both cases the movements or forces may be related to the upfolding of the Tethys-belt in the Mediterranean zone which, at least as far as Turkey, has a general east–west trend. This is supported by the fact that also in Turkey the main period of upfolding started at the end of the L. Eocene (Tromp, 1947), the main erosional unconformity being at the base of the M. Eocene.

We explained (Tromp, 1941) that, due to the upfolding of the Alps by north–south forces, in the more rigid regions north of Switzerland two shearing-fault systems can be expected : S.E.–N.W. system, known

as the *Hercynian-Thuringian* or *Saxonian Fault System* and a S.W.–N.E. system, known as *Variscan-Erzgebirge Fault System.* These fault systems could be created artificially also in the experiments discussed in the above-mentioned article.

It seems probable that a similar fault pattern was developed also in the more rigid areas (Tromp, 1943) south of the Balkans and of the Anatolian orogenic belt, after the upfolding started in the basal M. Eocene. Updoming itself creates a system of stretch-faults converging downwards. As the updoming in Egypt seems to have been strongest in Sinai and the areas east of the present Nile Valley, we could expect the greatest stretch-faults in these areas. A combination of both phenomena, shearing-fault patterns and stretch-faulting may have been the main cause of the formation of the Gulf of Suez depression.

The extensive basalt extrusions in the Oligocene of Egypt and also during later periods on the west coast of Arabia, along the graben-faults of Ethiopia, along the Dead Sea graben zone (e.g. west and north of Lake Tiberias and in Syria) indicate that these originally superficial Eocene fault-systems in the M. East must have reached the sima layer during the Oligocene and later periods as a result of further updoming during the U. Eocene. The updoming created a further relief in pressure and enabled the sima to become an active fluid which could extrude. Where two major opposing fault-systems were present very likely the mechanism described by S. Taber (1927) became important because the sial blocks were floating in a liquefied sima layer. Blocks bordered by faults which were converging downwards became graben zones, those bordered by diverging faults became horsts. As the fault-systems were not completely symmetrical, in reality tilted block movements must have taken place, the parts of the horst nearest to the graben becoming the topographically highest points. As a result of later erosion the pre-Cambrian basement was exposed on these highest edges, whereas further away from the graben faults younger formations can be found.

Further updoming and stretching created a fault pattern as was clearly shown by Cloos in a series of most illuminating experiments (Cloos, 1928, 1932, and 1936). As a result of these stretch-phenomena both *synthetic graben faults* (i.e. faults having the same tendency as the main edge-faults and increasing the general downthrow in the graben) and *antithetic faults* (i.e. faults counteracting the movements along the main faults) are formed.

Particularly in the region near Hammam Faraun and also further south splendid examples of these fault-patterns can be seen.

We fully realize that this synthesis of the origin of the Red Sea graben is far from complete. Many facts could not be given as they

are company secrets and several problems have not been solved yet. We have tried to compile only the main facts which may give a clue to the origin of the Red Sea graben, a zone which was probably not formed either by compression or stretch but by a complicated interaction of different fold and fault mechanisms.

REFERENCES

CLOOS, H., 1928. Über antithetische Bewegungen. *Geol. Rundschau*, 19, 246–251.

—— 1932. Zur Mechanik grosser Brüche und Gräben. *Zentralbl. f. Min., Abt. B*, 273–286.

—— 1936. *Einführung in die Geologie.*

KRENKEL, E., 1922. *Die Bruchzonen Ost Afrika's.*

TABER, S., 1927. Fault troughs. *Journ. Geol.*, 35, 577–606.

TROMP, S. W., 1937. On the mechanism of geological undulation phenomena . . . Sitjhoff Publ. Co., Leiden, Holland.

—— 1937. Das Gesetz von Helmholtz und seine Anwendung auf Geotektonik. *Zeitschr. f. Geoph.*, Jahrg. 13, 78–87.

—— 1941. New experiments of fault-tectonics and " Helmholtz " folding. *Geologie en Mijnbouw*, 65–72.

—— 1943. Micro-faunae of the U. Cretaceous and Tertiary sections (Arabian facies) in the Urfa and Gaziantep regions (S. Turkey). *M.T.A. Bull.*, sene 8, sayi 1/29, Ankara, 134–141.

—— 1947. A tentative classification of the main structural units of the Anatolian orogenic belt. *Journ. Geol.*, 55, 362–377.

—— 1949. Blockfolding phenomena in the Middle East. *Geologie en Mijnbouw*, 273–8.

—— 1950. Preliminary compilation of the macro-stratigraphy of Egypt (to be published in the *Proc. Roy. Geogr. Soc. of Egypt*).

Asterozoa and the Study of Palaeozoic Faunas

By W. K. Spencer

Abstract

This paper is an elaboration of the author's contribution to the 1938 *British Association* discussion on the distribution and migration of British Lower Palaeozoic faunas. It concerns mainly the faunas of Western Europe and North America and presents in summary the author's conclusions regarding faunal affinities and directions of immigration of the Asterozoan element in those areas. There is a notable agreement with Stubblefield's conclusions regarding the trilobite element, especially as concerns the Ordovician. The scope of the discussion is here extended to include notes on Devonian and Carboniferous faunas and some Cystid references. The paper concludes with some systematic notes, and three new generic names are proposed.

THE following observations are made in an endeavour to assist geologists in their reconstruction of the history of the Palaeozoic rocks. They are an elaboration of the notes (Spencer, 1938) contributed to a discussion on "The Distribution and Migration of certain Animal Groups in the British Lower Palaeozoic Faunas" held in Section C of the British Association Meeting of 1938.

As Dr. Stubblefield (1939, p. 49) has pointed out, "any conclusions made at the present stage are tentative and are offered as an incentive to research." The views presented here are in reasonably close agreement with those of the other contributors to the Cambridge discussion.

This contribution has been somewhat delayed because I wished to check observations upon the Asterozoa with those upon the limited number of Cystoidea which are available to me. Recently Regnéll (1948) has given a very detailed account of Cystid succession and migration. I am adding a few notes from my own observations upon the Cystoidea of S. France. Professor M. Thoral gave me every encouragement during my visit to Montpellier to study these together with the very important local Asterozoan faunas. I am greatly indebted to him for this kindly help. Dr. Stubblefield and Dr. Lamont have given me many helpful suggestions in the preparation of this communication.

To facilitate the discussion of these faunas, it has been found necessary to revise the classification of certain families, and to erect some new genera. This revision is given on pp. 405–408 under the heading "Systematic Notes".

The greater part of these studies is concerned with the faunas of Western Europe and North America. There has been considerable agreement on the geography of these regions during the early Palaeozoic. On the North were two shields, Laurentia and Baltica. East and west were two relatively stable platforms. Between the continental platforms there were geosynclinal basins which opened to the north between the continental shields into an epeiric sea which provided not only a passage way but a breeding ground for new faunas.

A map of the Ordovician geosynclines was given by Grabau (1940, pl. v). It seems probable that this may have to be modified considerably, especially that part relating to Europe (Regnéll, 1948, p. 9). O. T. Jones (1938) has made various suggestions relating to the character of the geosynclines in the Welsh and Scottish areas. J. S. Turner (1949) has put forward views upon the European Caledonides and the faunal communications which existed in the Lower Palaeozoic times. These latter seem to me to help very considerably when considering the starfish distribution in Tremadoc and Arenig times.

Biology of Starfish

The great majority of the Palaeozoic starfish fall into the two familiar groups, Asteroidea and Ophiuroidea. There is evidence of a third group of primitive starfish which I am hoping to describe shortly. In this third group the arm is in process of differentiation. The two important genera are *Chinianaster* Thoral (1935, p. 127 ; Tremadoc) and *Archegonaster* Jaekel (Upper Arenig).

Both the Asteroidea and Ophiuroidea have functional arms, but the manner in which the arms is constructed and used differs in the two groups. The arm in the Asteroidea has thick muscular walls, and is used in combination with the tube feet to convey food, mostly mollusca, to the mouth. The mollusc is seized by a number of tube feet, the arm then bends and brings the mollusc near to other tube feet. These in turn seize it and gradually the mollusc is brought to the mouth and engulfed by an everted stomach. The mollusc may be digested outside the body or withdrawn with the stomach into the body.

The Ophiuroidea have thin arm-walls. The muscles which are important are placed longitudinally between the ambulacralia. These tend to develop ball and socket joints and to be transformed into vertebrae. The ambulacralia of the earliest Ophiuroidea are but little modified, and it is only in later evolution that the snake-like arm is produced. It is then possible for the Ophiuroid to chase and capture food.

The early Ophiuroidea were not carnivores but deposit-feeders living on the rich supply of small food available near the bottom. Some recent Ophiuroidea live in this way, and have been seen to feed by pushing the bottom mud towards the mouth by means of their tube feet (Hunt, 1925). A considerable number, if not all, live like the living *Amphiura* in burrows with their arms flexed steeply and with the arm-tips emerging from the mouth of the burrow in search of food.

Mode of Preservation

The starfish skeleton readily disintegrates after death and the greater part of our knowledge is obtained from " complete " specimens preserved under special conditions. It is essential for preservation

that the animal should be encased rapidly. Starfish which have a burrowing habit fulfil these conditions. The animals died in their burrows. The burrows were kept open by the living activities of the animal and, when these ceased, the burrow was quickly filled in with mud. A large number of Ophiuroidea burrow and correspondingly the proportion of Ophiuroidea found in the fossil faunas is large. Modern Asteroidea never make a burrow but some, like the recent *Astropecten*, spend a considerable portion of their life just underneath the upper layers of the sea-bottom. Such Asteroidea have special modifications for respiration which can be readily recognized from the skeletal characteristics.

There seem to be special conditions associated with the starfish beds in the Upper Ordovician (Girvan), Silurian (Pentland Hills, and Leintwardine, Herefordshire), and the Bundenbach Slates of the Lower Devonian of the Rhine.

These conditions of preservation are dealt with in greater detail in sections which follow.

The Influence of Transgressions upon the Fauna

The Asterozoan faunas observed are not continuous developments of one and the same fauna. From time to time there are invasions of new faunas which may dominate and replace the older fauna. These invasions seem to come from an outside source. The suggestion which has gained ground is that they arrive from a breeding ground of new faunas, the epeiric seas at the mouth of the geosynclines.

This influx of new faunas is recognizable in many animal groups and at several intervals, occasionally in quick succession. Ulrich laid great stress on the studies of invading faunas as a whole. I have attempted to show some of these correlations of faunal elements in the following pages.

Grabau, in a stimulating account of faunal changes, recognizes a distinct rhythm influenced by orogenic movements. Du Toit (1937, p. 309) has suggested that the northern "shields" may have, under orogenic disturbance, approximated at one time and at another diverged. Such "see-saw" movements would allow periods of stability of faunas followed by new immigrations.

Tremadoc and Arenig

Starfish first appear in the Tremadoc and have a continuous history extending into the Arenig. They are distributed in an area which is bounded by an approximate triangle with an angle near the Pyrenees and a base stretching from South Wales to Bohemia. The base corresponds with the south border of the North English virgation of the European Caledonides as figured by Turner (1949, p. 292).

By far the greater number of the specimens have been found in two

localities, one near St. Chinian, S. France, and the other at Osek, Bohemia. Almost all the fossils are embedded in flint-like nodules rounded very much like pebbles. The nodules were formed around those parts of the fossil which were buried in the bottom-mud and contain the remains of the " burrowing " starfish of the period. The parts of the animal thrust out of the burrow to seek for food are missing.

The contemporary fauna from Wales and the Welsh Borderland is very scanty, but is interesting because it shows a distinct affinity with that of Bohemia.

The major elements in the fauna are :—

(1) The " primitive starfish " referred to below.

(2) Primitive Ophiuroidea which have their tube-feet seated between two ambulacralia as in the Asteroidea, not solely on one ambulacral as in the later Ophiuroidea which evolved a vertebral arm structure. Many primitive Ophiuroidea disappear from the record for a very considerable interval, reappearing later in the Silurian. A similar disappearance of faunal elements is noted below for some of the Cystidea.

Asteroidea are rare during these times.

Tremadoc

The Tremadoc transgression brings along with it the earliest known starfish (Family Chinianasteridae). They have a very distinctive primitive structure and some appear to have been ciliary feeders. There are two genera which have been figured by Thoral collectively as one genus, *Chinianaster* Thoral (1935, p. 127). I am describing shortly this material at greater length.

The same transgression is accompanied by other new faunas belonging to genera or groups of genera which appear for the first time. Amongst these are Cephalopods which Thoral insists have relations with forms from Korea and from N. America. There are several new non-Crinoid Pelmatozoa. These include *Mimocystites* Barrande, which with its ally *Macrocystella* Callaway has, at this horizon, an almost cosmopolitan distribution. Regnéll (1948, p. 11) says these genera occur not only in France, but in England, Bohemia, Bavaria, Greenland, Korea, and the South American Cordilleras. It is obvious therefore that there was a very wide occurrence of the transgression. Stubblefield (1939, p. 52) discussing the Tremadoc Trilobites supports this, stating " that earlier faunal affinities with Southern Europe lost in the Upper Cambrian are regained, but the main bulk of the fauna is of extra-European origin, some possibly American, and some possibly Asiatic ". A second non-Crinoid Pelmatozoan of this transgression is *Dendrocystis* Bather found at this horizon in Korea.

A third Cystoid brought to notice by Thoral and figured (1935, pl. x, fig. 3) as Cystid or Crinoid undet. has resemblances to *Trachelocrinus* described by Ulrich from the Upper Cambrian of Montana.

Lower Arenig

The French beds show that successive transgressions followed the Tremadoc transgression. These are represented by three zones in the Lower Arenig. Professor Thoral, up to the present, has described fully only the lowest zone, but he has kindly lent me the Asterozoa from the succeeding zones for examination and description.

The zone immediately succeeding the Tremadoc has a relict starfish fauna from that horizon. They are here accompanied by the earliest known Ophiuroid, *Palaeura jacobi* Thoral. The earliest known Arenig graptolites arrived. Thoral points out that these have affinities with graptolites found in N. America and the Lake District.

Amongst new constituents of the fauna are two Cystids, *Cothurnocystis* Bather and *Lingulocystis* Thoral; these genera are not seen again until the Ashgillian of Girvan.

A small find of Asterozoa has been made in the Lower Arenig of Ramsey Island, South Wales. Two Asteroidea of a primitive macrophagous type are represented by several specimens. One of these is *Petraster ramseyensis* Hicks sp. (see Note 1), the second remains to be described. This type of Asteroidea is absent from the French beds but is met again, with other more advanced forms, in the Upper Arenig of Bohemia. Both these faunas are early representatives of the Asteroidea and Ophiuroidea which become predominant in the Middle Ordovician.

Professor Thoral has collected some Ophiuroidea from the zones immediately succeeding the basal Arenig zone. They are as yet undescribed. I think that they contain ancestors of the *Euzonosoma* Spencer—*Encrinaster* Haeckel group which arrive in Britain in the Upper Ordovician (*vide infra*).

Upper Arenig: Llanvirn

A very considerable Asterozoan fauna has been collected from the $D\gamma_1$ beds of Osek, Bohemia. The fauna has two constituents:

(1) A large number of specimens belonging to a few genera, allied but not identical with the primitive Asteroidea and primitive Ophiuroidea of the earlier French beds. These primitive constituents include a "primitive starfish", *Archegonaster* Jaekel, and two primitive Ophiuroidea, *Palaeura* Jaekel emend. Schuchert and *Eophiura* Jaekel emend. Schuchert. Short descriptions of these forms have been given by Jaekel (1903, pp. 109, 107). By the courtesy of the Prague Museum

I have been able to make a thorough examination of the material. A relation is a species of *Palaeura* from the Upper Arenig of Shropshire. It serves to emphasize the continuity of an Anglo-Welsh Bohemian basin.

(2) A few representatives of more advanced Asteroidea and Ophiuroidea which seem to be early immigrants of faunas which become prominent in succeeding beds. These include two Asteroidea, one a primitive " *Hudsonaster* ", the other an Urasterellid (*Bohemaster primula* of Jaekel). The small Ophiuroid (*Hypophiura* Jaekel, 1923, p. 349), is a small *Hallaster* ; *Petraster* is also found. It was noted above that it was found also in the Lower Arenig of Wales. It seems to be an even earlier immigrant of this same invasion.

The Trilobites show even more clearly the extent of this basin (Stubblefield, 1938, p. 54). Stubblefield also notes that the Trilobites of this fauna have a partial Portuguese development. He also remarks that there are " other trilobites in Shropshire and Wales which are not known in this ' Bohemian ' fauna, notably *Platycalymene* . . . and *Ogygiocaris* . . .". Like the second Asterozoan fauna of the Bohemian basin they become prominent in the succeeding beds.

Middle Ordovician

The base of the triangle of distribution has now lengthened far to the East and to the West ; to the East as far as Turkestan, to the West to the St. Lawrence valley. Most of the Asterozoa in West Europe are in a narrow area to the south of this base. In North America there are two " outliers ", one in Kentucky and the other in the Middle West (Ohio Basin). In Britain, the Girvan area to the west of Scotland appears to be another " outlier ".

The fauna has become more modern ; the forms are definitely built more like recent starfish. The archaic forms *Chinianaster* Thoral, *Archegonaster* Jaekel, *Eophiura* Jaekel-Schuchert and *Palaeura* Jaekel-Schuchert, which form so large a proportion of the earlier forms have disappeared. The centre of much of the new differentiation appears to be to the west of Britain.

The base line is shown by two genera, *Stenaster* Billings and *Protopalaeaster* Hudson. *Stenaster* is found in Turkestan, Wales, Ireland, and the St. Lawrence valley, whilst *Protopalaeaster* (see Note 2) is found in Turkestan (*Ordoviciaster* of Fedetov, 1936, p. 4), the Welsh Borderland, and the St. Lawrence (*P. narrawayi* Hudson and " *Hudsonaster* " *matutinus* Hall sp.).

Other genera helping to reconstitute the line are *Petraster* Billings [*Uranaster* Gregory] in South Ireland and the St. Lawrence ; *Bohemura* Jaekel in the Welsh Borderland, Bohemia, and Turkestan ; *Salteraster* Stürtz of the St. Lawrence, Newfoundland, and Wales.

Salteraster belongs to a group of the Asteroidea, the " Urasterellids ", which apparently differentiated in the St. Lawrence area and were accompanied on their eastward migration by the Edrioasteroid, *Edrioaster*.

Several genera appear to be confined to the centre of the base line, *Siluraster* Jaekel (= *Caractacaster* Spencer; see Note 3) Welsh Borderland and Bohemia, *Protaster* Forbes, *Baliactis* Spencer, and *Platanaster* Spencer, the Welsh Borderland only. Relatives of these latter two genera disappear from the records until the Silurian and Lower Devonian.

The genera confined to the west are the Ophiuroids *Taeniaster* Billings and *Hallaster* Stürtz. The former appears to have evolved here, the latter has been noted as occurring in the Upper Arenig.

Further information about the base line appears to be given by the trilobite *Basilicus* which Fedetov notes as occurring alongside the starfish in Turkestan. Stubblefield (1939, p. 54) states that this trilobite was an immigrant into the Llandeilo of the Anglo-Welsh area, and is known also from South Chosen and with less certainty from the Chazy of North America. This suggests that the base in the east continued beyond Turkestan into N. China.

The Cystid base line runs further south, through Brittany, Bohemia, to Burma. This is the line of distribution of the " *Aristocystis* " faunas. *Aristocystis* is found in the extreme west in the Llandeilian of Brittany and in the extreme east in the Llandeilian of the Burma-Chinese border. It has a local development in the Upper Llandeilian and Caradocian of the west. This local development is found not only in Brittany and Bohemia, but also in Portugal, Spain, and Morocco (Regnéll, 1948, p. 32). It has not been found in the Anglo-Welsh faunas. A possible occurrence for it would be in the third Llandeilo fauna of Stubblefield (1939, p. 55), a Cornish Ordovician fauna in which Stubblefield states that *Synhomalonotus* returns to Britain in association with an undescribed Calymenid and a Cheirurid of Bohemian and Iberian affinities.

Starfish have not yet been recorded from this southern area except in Bohemia, and there the fauna is scanty and confined to the two genera *Siluraster* and *Bohemura* Jaekel.

Other Faunal Centres

There is evidence that there was a second distribution centre which provided some of the Middle and Upper Ordovician faunas and the greater part of the Silurian and Devonian faunas. The centre was in position to send emigrants into North America, Britain and West Europe, and Australia. The new immigrants were accompanied by Arenig Cystids.

The first appearance of this fauna appears to be in the Black River of the Ohio basin. This contains the "Urasterellid" *Ulrichaster* gen. nov. (see Note 4) and the Edrioasteroid *Pyrgocystis* Bather. *Ulrichaster* next appears in the Lower Silurian of the Pentland Hills and in the Silurian of Australia, and *Pyrgocystis* in the Upper Ordovician of Girvan and the Silurian of the Baltic. The "*Hudsonaster*" ("*Protopalaeaster*" of Sardeson, not *Protopalaeaster* G. W. Hudson) is near to a "*Hudsonaster*" found in the $D\gamma_1$ beds of Bohemia.

It may be that the Asteroid *Baliactis* Spencer and *Platanaster* Spencer of the Caradocian of the Welsh Borderland belong to this fauna. *Baliactis* (see Note 5) is a probable member of the Australian Silurian fauna and is found in the Lower Devonian (Bundenbach Slates). *Platanaster* has two near relations in the Bundenbach Slates (*Palasteriscus* Stürtz and *Echinasterella* Stürtz). These are the only recorded occurrences of these genera.

There may be a third centre, characterized by the *Euzonosoma-Encrinaster* group. These appear in the Upper Ordovician of Girvan, are not recorded from Australia, and do not appear in America until the Upper Devonian.

Upper Ordovician

New lines of communication open up and some of the older ones close down. No starfish have been found in the Welsh Ashgillian, and the Cystids there have a close similarity with those of the Baltic. On the other hand, the contemporary beds from Girvan, on the south-west coast of Scotland have abundant starfish and Cystids. The latter are quite distinct from those of the Baltic. The starfish fauna is partially derived from the Middle Ordovician and partly from new invasions. In the American beds, the greatest development is in the Ohio basin, the Maysvillian, and the Cincinnatian.

The fauna contains two elements :—

(1) That derived from the Middle Ordovician of the same basin. It includes a "*Hudsonaster*", *H. incomptus* (Meek) with an axillary ossicle similar to that of the "*Protopalaeaster*" of Sardeson.

(2) Two new groups of Asteroids belonging to the genera *Mesopalaeaster* Schuchert and *Promopalaeaster* Schuchert. This invasion also reaches Girvan, where it is accompanied by an Ophiuroid *Drepanaster* found in America in the Utica shale. *Promopalaeaster* is also found in the Silurian of Australia.

In Scotland the material for analysis of the Girvan fauna is abundant. Considerably more than a thousand specimens of starfish have been collected, and other groups are well represented. The collections have been made mainly by Mrs. Gray, the Misses Gray, Mr. Begg, and Dr. Lamont, who all have been careful to preserve counterparts ; in consequence the identification of the specimens can be made accurately.

The earliest analysis of the faunas was made by Bather (1913), and was based largely upon his work on the Cystids. Bather drew three main conclusions :—

(1) That the faunas showed a marked break from the Baltic faunas, although approximately contemporaneous Welsh and East Irish faunas showed distinct Baltic affinities.

(2) That there was a North American element, marked particularly by *Pleurocystites* Billings (= *Pleurocystis* Carpenter) and *Cheirocrinus* Eichwald.

(3) There was a European element to be traced to the Bohemian faunas ; *Dendrocystites* Barrande (= *Dendrocystis* Bather) and *Cothurnocystis* Bather were derived from this fauna.

At this time the faunas from the St. Chinian area of the south of France were scarcely known. Thoral (1935) has shown that these beds contain *Dendrocystis* and a *Cothurnocystis*. The *Cothurnocystis* is very similar, indeed, to *C. elizae* from Girvan, and distant from the Bohemian *Ceratocystis*. A third Cystid *Lingulocystis* from the French beds has been found by the Misses Gray at Girvan. This is a form which, like *Cothurnocystis*, cannot be mistaken for anything else. A fourth Cystid, a small *Hemicystites* Hall (= *Hemicystis*) described by Thoral, can be matched by a similar specimen collected by Dr. Lamont from Girvan.

It thus seems clear that the European element of Bather is derived from the French Arenig faunas rather than from those of Bohemia. This conclusion receives some support from the starfish.

The starfish faunas can be analysed by the same methods as those employed by Bather. There are several elements in the fauna :—

(1) From the Mid-Ordovician ; this includes *Protopalaeaster* Hudson, *Cnemidactis* Spencer, *Urasterella* McCoy, and *Stenaster* Billings. The genera are all found in North-East America. There are no typical Welsh or Bohemian elements, such as *Siluraster* Jaekel, *Protaster* Salter, and *Bohemura* Jaekel.

(2) New immigrants also recognizable in the Upper Ordovician of North America. These include *Mesopalaeaster* Schuchert, *Promopalaeaster* Schuchert and *Drepanaster* Whidborne, *Yarravaster* gen. nov. (see Note 6) and *Urosoma*, new elements in the North American beds. Few of the species seem to be identical in the two areas. It would seem that they derived their faunas from a common source, possibly from two centres.

(3) New immigrants related to the Arenig faunas ; *Euzonosoma* Spencer and *Encrinaster* Haeckel related to *Stenaster*-like Ophiurids in the collection of Professor Thoral ; *Archophiactis* Spencer related to the primitive starfish *Chinianaster* Thoral.

(4) New immigrants with untraced ancestry, found also in the Silurian of Australia ; *Lapworthura* Gregory and *Furcaster* Stürtz.

It seems probable that some of the members of the fauna (4) came from a reservoir to the east which also contributed to the Australian faunas (see Silurian of Australia).

Regnéll (1948, p. 36) thinks that the Cystid *Caryocrinites* Say arrived in the Upper Ordovician of the Baltic from a Northern Sea which sent the richly developed Middle Silurian *Caryocrinites* faunas of North America.

Silurian of Australia

Withers and Keble (1934) have described a considerable Australian Silurian fauna which has a marked resemblance to the contemporary faunas of North America and West Europe. I have given a review of the authors' identifications in Note 5. I am suggesting the following correlations of the Northern faunas with those of Australia :—

Middle Ordovician.

Ulrichaster gen. nov. (see Note 4) Black River, U.S.A., and *Baliactis* Welsh Borderland.

Upper Ordovician.

Promopalaeaster, *Urosoma*, *Yarravaster* gen. nov. (see Note 6), both North America and Girvan ;

Lapworthura, *Furcaster* Stürtz, Girvan only ;

Archophiactis Spencer, Girvan closely similar to

Stürtzura Gregory, Australia (not in America) ;

Petraster North America only.

Lower Silurian.

Phillipsaster gen. nov. (see Note 4). North America and English Midlands ;

Yarravaster gen. nov. (see Note 6). North America ;

Ulrichaster gen. nov. (see Note 4), *Crepidosoma* Spencer, *Furcaster* Stürtz, *Eoactis* Spencer, *Schuchertia* Gregory, *Taeniactis* Spencer. Scotland, Pentland Hills (Gutterford Burn).

Middle Silurian.

Lepidaster Forbes, *Palasterina* McCoy. English Midlands and I. of Gotland ;

Furcaster. North America.

Upper Silurian.

Lapworthura Gregory, *Furcaster*, *Schuchertia*, *Yarravaster* gen nov. Welsh Borderland ;

Palasterina, *Urosoma* Spencer. Lake District.

Lower Devonian.

Schuchertia, *Urosoma*, *Baliactis* Spencer, *Eoluidia* Stürtz. Lower Devonian of the Rhine.

The following species groups have not been described from

Australia : " *Hudsonaster*," " *Mesopalaeaster* " as redefined, and the " *Euzonosoma-Encrinaster* " group.

British Silurian

The British Silurian faunas are Lower Silurian, Alfrick, Worcs., and Gutterford Burn, Pentland Hills (Lamont, 1947) ; Middle Silurian, Wenlock of the English Midlands ; Upper Silurian, Leintwardine of the Welsh Borderland and the Starfish Bed of the Lake District.

The major parts of these faunas have been derived from the same source as that which provided the Australian fauna. The Leintwardine fauna seems to be more akin to that of Girvan than do the remaining faunas. *Lapworthura* and *Furcaster* are abundant in both, whilst only *Furcaster*, and that rarely, is found in the other localities. *Protaster* is absent both from Girvan and Leintwardine whilst present in the Wenlock and the Lake District.

There is a reappearance of Arenig Cystids in the Wenlock beds corresponding to a similar association of Cystids and Starfish at Girvan. The Wenlock Cystids were characteristic of the Arenig of the Baltic and Bohemian provinces just as those of Girvan were of the South of France.

The physical conditions are of interest. The starfish are mainly confined to small areas associated with coral reefs which bordered a North Atlantic Continent. A reconstruction of the environment has been made by Grabau. He states (1932, p. 422) that " the earlier reef series shows its proximity to the land by the fact that, in the lagoons between the reef mounds, terrestial or semiterrestial organisms, the Eurypterid *Pterygotus* and the scorpion *Palaeophonus* were found together with marine organisms ". Lamont has referred recently to the Eurypterids at Gutterford Burn. The lagoon conditions at Leintwardine have also been described by Hawkins and Hampton (1927, p. 580).

Many of the Starfish have characters possibly associated with such lagoon condition. There is a distinct loss of skeleton in genera which earlier had a well developed skeleton (in their Arenig ancestors). Such genera are *Stürtzaster*, *Rhopalacoma*, and *Bdellacoma*, all primitive Ophiuroidea related to the primitive Ophiuroidea of the Arenig. The recent Euryalae which live in quiet waters show the same loss of skeleton.

Devonian

The faunas of the Lower Devonian of the Eifel show two facies, the first associated with the fine mudstones of the Bundenbach Slates ; the second with the coarser grained rocks of the Coblenz Series.

The Bundenbach starfish fauna is more varied in its constituents than in any other locality. The specimens have been pyritized and

this has not only preserved the ossicles but the integument surrounding them. In consequence, there is perfect preservation of types which had a weak skeleton, liable to be dispersed under less favourable circumstances.

The following seem to be the chief links with other faunas :—

(1) *With Girvan.* (*a*) The Ophiuroidea with slender side-shields and opposite ambulacralia : *Hallaster*, *Furvaster*, and *Eospondylus* Gregory. This latter genus links with *Lapworthura*.

(*b*) The Ophiuroidea with thick side-shields : *Euzonosma*.

(*c*) The Ophiuroidea with slender side-shields and alternate ambulacralia : *Taeniaster* Spencer (*Bundenbachia* Stürtz pars).

(2) *With the mid-Ordovician of the Welsh Borderland* :—

(*a*) The Ophiuroid *Bohemura* (but not *Protaster*).

(*b*) The primitive Asteroidea *Palasteriscus* and *Echinasterella* Stürtz, both akin to the earlier *Platanaster* and *Baliactis* common to both areas.

(3) *With the Arenig of South France.—Helianthaster* and *Medusaster* Stürtz, *Bdellacoma*, and *Stürtzaster*. Specimens of both these latter genera are rare. They were common at Leintwardine.

In addition, there is *Palasterina*, a comparative newcomer to the area.

This fauna is almost devoid of Asteroidea, only one or two specimens having been found.

The second facies in a coarser matrix has proportionately more Asteroidea. These Asteroidea have near relationship with the American and Girvan " *Mesopalaesters* ". They include *Spaniaster* Schöndorf, *Eifelaster* Schöndorf, *Rhenaster* Schöndorf, and *Xenaster* Simonovitsch emend. Schöndorf.

Some of the forms (e.g. *Eifelaster*) show a broadening of the arm leading to the pentagonal Asteroidea of the Mesozoic.

The Ophiuroidea belong to the Euzonosomatidae and closely resemble those of Girvan. Species of both *Euzonosoma* and *Encrinaster* are found.

A mollusc-eating Asteroid, *Devonaster*, not unlike the Coblenz *Xenaster*, occurs in the M. Devonian (Hamilton) of North America. More than 100 specimens were found at Saugertier close to a mollusc bank. They were of all sizes and ages and had obviously congregated to feed.

The Upper Devonian of North America (Naples and Chemung beds) has an Asterozoan fauna of a " still " water type comparable with the above. It includes a Euzonosomatid (*Aspidosoma* sp. of Ruedemann), *Lepidasterina* Ruedemann, and *Lepidasterella* Schuchert. This is the only known occurrence of Asterozoa of this type in North America. There is also a local development of *Urasterella* shown by several species. One of these " *U.*" *lutheri* appears to be identical with *Palastropecten zitteli* of the Bundenbach (see Note 4).

Carboniferous

An Asterozoan fauna is found in the basal Carboniferous of North Devon. It contains a remnant fauna, *Protaster*, *Drepanaster* Whidborne, and *Encrinaster* Haeckel together with new forms. The latter include two genera previously known only from the Lower Carboniferous of North America, *Onychaster* Meek and Worthen, and *Calyptactis* Spencer. There is also a new Urasterellid *Protarthraster* (Spencer, 1918, p. 164). The aboral surface of this genus possesses strongly ridged ossicles. Related forms are *Calliasterella* Schuchert from the Russian Permo-Carboniferous and *Arthraster* Forbes, the last surviving Urasterellid, from the Upper Chalk.

Onychaster is also found in the L. Carboniferous of Scotland. There is a great gap in our knowledge of the fossil Asterozoa from the Lower Carboniferous until well on in the Mesozoic.

SYSTEMATIC NOTES

Note 1.—*Petraster* Billings 1858 and *Uranaster* Gregory 1899.

It now seems to me that these genera are identical, so that *Uranaster* becomes a synonym of *Petraster*, and the species described by me (Spencer, 1918, p. 109, and 1916, p. 105) as *Uranaster ramseyensis* (Hicks) and *U. kinahani* (B ily) should be known as *Petraster ramseyensis* (Hicks) and *P. kinahani* (Baily) respectively.

Note 2.—*Hudsonaster* Stürtz 1900.

This genus was founded by Stürtz upon *Palasterina rugosa* Billings from the Upper Ordovician of Anticosti Island. The name was adopted by Schuchert (1915, p. 53) for a number of North American species, some of which were withdrawn from *Palaeaster*. About the same time I described (Spencer, 1916, p. 69) some new material from Britain and proposed three new genera all related to "*Hudsonaster*". The genera were *Girvanaster* and *Belaster*, both from the Upper Ordovician of Girvan, and *Coccaster*, from the Middle Silurian of Leintwardine. Raymond (1921) showed that the genera could be best defined from the shape of the axillary inferomarginal, and there is no doubt that the character is very important. Unfortunately, we know nothing about this ossicle in the single specimen of the type species of *Hudsonaster*, for only the aboral surface is exposed.

In recent years new material has been lent to me. With the aid of this new material it is possible to make the following groups :—

Group 1.—Axillary inferomarginalia only slightly differentiated from neighbouring inferomarginalia.

New material from the $D\gamma_1$ of Bohemia.
The "*Protopalaeaster*" of Sardeson from the Ohio basin.
"*Hudsonaster*" *incomptus* (Meek).

Group 2.—Axillary well differentiated, longer than broad.

(*a*) Axillary rhomboidal.
Girvanaster Spencer (1916, p. 70).

(*b*) Axillary polygonal.
Protopalaeaster narrawayi Hudson (1912, p. 25).
"*Hudsonaster*" *matutinus* (Hall).
Ordoviciaster Feodotov (1936, p. 4).
Belaster Spencer (1916, p. 73).

All these forms in Group 2 seem to me to belong to one lineage, and therefore are grouped under *Protopalaeaster* Hudson (1912, p. 25), since this generic name holds priority. Raymond (1921, p. 167) selected "*H.*" *matutinus* as the type of his new genus *Macroporaster*. I consider that this name should lapse

into the synonymy of *Protopalaeaster*, though *Macroporaster nylanderi* Raymond (1921, p. 168) from the Silurian of Maine may belong to a new genus.

Group 3.—Axillary well differentiated but broader than long.
Coccaster Spencer (1916, p. 75).

Note 3.—*Siluraster* Jaekel and *Caractacaster* Spencer.

The type-species of *Siluraster* Jaekel 1903 by monotypy is *S. perfectus* Jaekel. Two illustrations of this species were given by Jaekel (1903, p. 108, text-figs. 2–3) : that of the mouth-parts (text-fig. 3) can be recognized as a portion of Specimen F in the Narodni Museum, Prague, and this is selected as the lectotype of the species *S. perfectus*. *Caractacaster* Spencer (1916, p. 80) with one species *C. caractaci* (Gregory) is undoubtedly a synonym.

Note 4.—" *Urasterella*."

The following groups can be recognized :—

A. Mid-radius of aboral surface of arm with two rows of ossicles.
Ulrichaster gen. nov. for type species *Urasterella ulrichi* Schuchert (1915, p. 183, pl. 29, fig. 1, pl. 30, figs. 6–7) from the Ordovician of Minnesota. Other species in this genus are *Salteraster biradialis* Withers and Keble (1934, p. 237, pl. xi, fig. 5) from the Silurian of Victoria, Australia, and *Urasterella gutterfordensis* Spencer (1918, p. 144, pl. x, figs. 2–3) from the Silurian (Gala-Tarannon) of Pentland Hills, Scotland.

B. Mid-radius with one row of ossicles.
(*a*) With ossicles between radialia and marginalia similar.
With aboral surface highly swollen.
Salteraster Stürtz, including *S. huxleyi* (Billings) from the Chazy of Newfoundland, *S. asperrimus* (Salter) from the Caradoc of the Welsh Borderland, and *S. grandis* (Meek) from the Richmond of Indiana and Ohio.
Aboral surface of arm moderately swollen.
Phillipsaster gen. nov. for type-species *Salteraster ? coronella* Spencer (1918, p. 153, pl. xi, fig. 6) from the Upper Llandovery of Worcs. Other species in this genus are *Urasterella ruthveni* mut. *arisaigensis* Ruedemann (1916, p. 46, pl. 11, figs. 5–6, pl. 12, fig. 3) from the Silurian of Nova Scotia, and *Salteraster selwyni* (McCoy), Withers and Keble (1934, p. 235, pl. xi, figs. 1–2) from the Silurian of Victoria.

(*b*) With ossicles between radialia and marginalia differentiated.
Urasterella McCoy, including *Urasterella grayae* Spencer from the Upper Ordovician of Girvan, *U. ruthveni* (Forbes) (Spencer, 1918, p. 140) from the Silurian of the Lake District, *U. ruthveni*, var. *leintwardinensis* Spencer (1918, p. 142) from the Silurian of the Welsh Borderland, *U. asperula* (Roemer) (Schuchert, 1915, p. 188) from the Lower Devonian of Germany, and *U. montana* (Stschurowsky) Schuchert, 1915, p. 189 (Spencer, 1918, p. 147) from the Permo-Carboniferous of Russia.

C. No ossicles of aboral surface of arm differentiated.
Palastropecten Stürtz (1886, p. 88), including the species *Urasterella lutheri* Clark, J. M.
Palastropecten zitteli Stürtz (1886, p. 88) from the Devonian of Germany.

Note 5.—The Australian Silurian starfish described by Withers and Keble (1934).

Hudsonaster australis W. & K. This is not a " *Hudsonaster* ". It lacks a central apical cap and the axillary is unlike that of any of the " *Hudsonaster* " group. The figures suggest a resemblance to the Wenlock genus *Lepidaster* Spencer.

Caractacaster yarraensis W. & K. The axillary is quite unlike that of *Siluraster* (= *Caractacaster*). The apical surface, as shown pl. x, fig. 2, is very characteristic of a group found also in North America and Britain. I have suggested the generic name *Yarravaster* for this group (see Note 6).

Promopalaeaster meridionalis (Etheridge fil.). The figures and descriptions are those of a typical *Promopalaeaster*. The authors suggest comparisons with *P. wykoffi* (Miller and Gurley) from the Upper Ordovician of the U.S.A.

Petraster angustior W. & K. and *P. richi* W. & K. The apical surface shows a typical "*Petraster*" structure. Both show some resemblance to the "Petrasters" of the Upper Ordovician of the U.S.A.

Palasterina flemingtonensis W. & K. The figure given, pl. xi, fig. 3, and the description, suggest that this is a species of *Baliactis* Spencer.

Palasterina stachi W. & K. The description suggests an *Eoactis*, especially the statement that the interbrachial angles are "characterized by a large interbrachial marginal plate, which is convex and hexagonally stellate . . ." The specimen described by me as *Palasterina wenlocki* is almost certainly also an *Eoactis*. It has this same characteristic interbrachial plate.

Salteraster selwyni (McCoy) and *S. biradialis* W. & K. See note 4, where the first is placed in a new genus *Phillipsaster* and the second in a new genus *Ulrichaster*.

Schuchertia junori W. & K. and *S. macrarta* W. & K. Both show the "*Schuchertia*" structure. The figure pl. x, 3, suggests that the multi-armed Wenlock *Lepidaster* may be derived from *Schuchertia*.

I have no comments on the following: *Stürtzura brisingoides* (Gregory), *Taeniactis yeringae* W. & K., *Crepidosoma kinglakensis* W. & K., *Lapworthura miltoni* (Salter), *Stürzaster* aff. *mitchelli* Etheridge, *Furcaster leptosomoides* (Chapman), *Eospondylus tenuis* W. & K., and cf. *Aganaster gregarius* (Miller and Worthen). All have typical characteristics.

Hallaster parvus W. & K. The figure given, pl. xi, fig. 5, suggests a species of *Urosoma*. It certainly is not a *Hallaster*.

Furcaster bakeri W. & K. also seems to be a *Urosoma*.

Note 6. Sub-family Mesopalaeasterinae.

Schuchert (1915, p. 73) proposed a new family, the Promopalaeasteridae, for a number of North American Asteroidea which mostly belonged to the Upper Ordovician and Lower Silurian. The family was subdivided into three sub-families, the Mesopalaeasterinae characterized by two ossicles in the axillary arm areas, the Promopalaeasterinae, with more than two ossicles in that area, and the aberrant Anorthasterinae. The definition holds if the oral surface of the arm is known. Difficulties arise if the fossil is known only from the aboral surface and a number of forms with wide divergence in aboral characters were grouped by Schuchert as probable "Mesopalaeasters".

New material suggests that it has become possible to define the aboral characters more exactly and to confine the Mesopalaeasterinae to species which show the oral characters of Schuchert and aborally have prominent radialia and superomarginalia separated by numerous small ossicles placed laterally to the radialia.

Defined in this way, two species-groups can be recognized in the Upper Ordovician-Lower Silurian. The first group is characterized by well-produced arms, the second by short wedge-shaped arms. The type-species of Schuchert's genus *Mesopalaeaster M. shafferi* (Hall) belongs to the first group, as also does *M. primus* Spencer (1916, p. 84) and *M. complicatus* Spencer (1916, p. 87) from the Upper Ordovician of Girvan and the Devonian form *Devonaster* Schuchert (1916, p. 87). The second group has American, Australian, and British members. The American member is *M. parviusculus* (Billings) (Schuchert, 1915, p. 87) from the Lower Silurian, known only from the oral surface. The British members are two new specimens from Girvan. These orally exactly resemble *M. parviusculus* and have counterparts which show the upper arm surface. These have a very characteristic appearance, the wedges standing out stiffly from a large disc. The "*Mesopalaeaster*" from Gutterford Burn described by me as *Mesopalaeaster* ? sp. shows the character well (Spencer, 1916, pl. ii, fig. 3). The species from the Australian Silurian, described by Withers and Keble (1934, p. 223, pl. x, figs. 1–2, text-figs. 2, 4) as *Caractacaster yarraensis* clearly belongs to this group. Their photograph given (op. cit., pl. x, fig. 2) is most convincing. The diagram of the axillary

ossicle given as Text-fig. 4 is quite unlike that of a *Caractacaster*, but may well be the double axillary with the suture between the ossicles difficult to recognize.

I am suggesting the generic name **Yarravaster** gen. nov. to include this species-group with *Caractacaster yarraensis* Withers and Keble as type-species, based on the illustrated specimens mentioned above.

REFERENCES

BATHER, F. A., 1913. Caradocian Cystidea from Girvan. *Trans. Roy. Soc. Edinburgh*, xlix, 359–529.

DU TOIT, A. L., 1937. *Our Wandering Continents*. Oliver and Boyd, London. pp. xiii and 366.

FEDETOV, D. M., 1936. Zur Morphologie und Evolution der Seesterne und Ophiuren des unteren Silur. *Trav. Inst. paléozool. Acad. U.R.S.S.*, v, 3–33.

GRABAU, A. W., 1940. *The Rhythm of the ages; Earth History in the Light of the Pulsation and Polar Control Theories*. Peking. 561 pp., 126 figs., 25 pls. and maps.

HAWKINS, H. L., and HAMPTON, S. M., 1927. The occurrence, structure, and affinities of *Echinocystis* and *Palaeodiscus*. *Quart. Journ. Geol. Soc.*, lxxxiii, 574–600.

HUDSON, G. H., 1912. A fossil starfish with ambulacral covering plates. *Ottawa Naturalist*, xxvi, 21–52.

HUNT, O. D., 1925. The food of the bottom fauna of the Plymouth Fishing Grounds. *Journ. Marine Biol. Assoc.*, Plymouth, xiii, 560–599.

JAEKEL, O., 1903. Asteriden und Ophiuriden aus dem Silur Böhmens. *Zeits. deutsch. geol. Ges.*, lv, Protokolle, 106–113.

—— 1923. Zur morphogenie der Asterozoa. *Palaeontol. Zeits.*, v, 344–350.

JONES, O. T., 1938. On the evolution of a geosyncline. *Quart. Journ. Geol. Soc.*, xciv, pp. lx–cx.

LAMONT, A., 1947. Gala-Tarannon Beds in the Pentland Hills, near Edinburgh. *Geol. Mag.*, lxxxiv, 193–208, 289–303.

RAYMOND, P. E., 1921. A new fossil starfish from New England. *Proc. Boston Soc. Nat. Hist.*, xxxvi, 165–170.

REGNÉLL, G., 1948. An outline of the succession and migration of non-crinoid pelmatozoan faunas in the Lower Palaeozoic of Scandinavia. *Ark. Kemi Min. Geol. Stockholm*, xxvi A, No. 13, 1–55.

RUEDEMANN, R., 1916. Account of some new or little-known species of fossils, mostly from Paleozoic Rocks of New York. *New York State Mus. Bull.* 189, 7–97.

SCHUCHERT, C., 1915. Revision of Paleozoic Stelleroidea, with special reference to North American Asteroidea. *U.S. Nat. Mus. Bull.* 88, 1–311.

SPENCER, W. K., 1914–40. The Palaeozoic Asterozoa, parts i–x. *Palaeont. Soc. London.*

—— 1938. The distribution and migration of certain animal groups in the British Lower Palaeozoic Fauna. 4.—The Starfishes and Cystids. *Rep. Brit. Assoc. Adv. Sci., Cambridge*, 1938, p. 415.

STUBBLEFIELD, C. J., 1939. Some aspects of the distribution and migration of Trilobites in the British Lower Palaeozoic Faunas. *Geol. Mag.*, lxxvi, 49–72.

STÜRTZ, B., 1886. Beitrag zur Kenntniss palaeozoischer Seesterne. *Palaeontographica*, xxxii, 75–98.

THORAL, M., 1935. *Contribution a l'étude paléontologique de l'Ordovicien Inférieur de la Montagne Noire*. Montpellier. pp. 1–362.

TURNER, J. S., 1949. The deeper structure of central and northern England. *Proc. Yorks. Geol. Soc.*, xxvii, 280–297.

WITHERS, R. P., and KEBLE, R. A., 1934. The Palaeozoic Starfish of Victoria. *Proc. Roy. Soc. Victoria*, xlvi, 220–249.

—— —— 1934. The Palaeozoic Brittle-Stars of Victoria. *Proc. Roy. Soc. Victoria*, xlvii, 196–212.

Sandy Gypsum Crystals from Berbera, British Somaliland

By W. A. MACFADYEN

(PLATE XIX)

ABSTRACT

Gypsum crystals containing 62 per cent by volume of sand are described from a late Raised Beach, where they were found by digging shallow coastal wells. An account is given of their crystallographic form and of the circumstances in which they have been produced. Gypsum has not only been deposited in the voids of the sand but has even moved the individual grains apart. A review is given of earlier records of sandy gypsum crystals, sometimes called " desert roses ", and comparison is made.

CRYSTALS incorporating a large proportion of sand have long been known ; they are stated to be usually of calcite, which are the most common, or of baryte or gypsum. Sandy rock-salt crystals have also been found, and there is a mention without reference of sandy celestine. What may have been the first to be described were incorrectly called " crystallized sandstone ", really sand-filled calcite crystals, found in Oligocene sands at Bellecroix in the Forest of Fontainebleau, near Paris. According to Lacroix (1901, p. 516) their true nature was recognized by Romé de l'Isle in the year 1774.

The terms " poecilitic " (Lacroix, 1901) and " ophitic " have been used in their description, but Dr. Campbell Smith considers these epithets to be inappropriate to crystals of this nature. The simple term " sandy " appears unexceptionable, in the sense of one of its principal meanings, given by the *Shorter Oxford English Dictionary* as " containing a large proportion of sand ". It was thus used by Vatonne in 1863, and has since been used by some later authors.

In the scattered literature it is rare to find that all aspects of this kind of crystallization have been adequately treated, namely the crystallography, the content and type of the sand, chemical analysis and temperature of the water in which the crystals grew, and the geological age and field relations. In some cases such treatment is manifestly impossible, but in others more complete description might well have been given.

Sandy gypsum crystals, some from their rosette-like intergrown form and provenance fancifully called " desert roses ", are recorded so far as I have found, from few localities in widely scattered parts of the world, detailed below. Thus, though often abundant where they occur, they are by no means commonly encountered. They seem generally to characterize arid regions, but must be restricted to places with an

adequate source of calcium sulphate in otherwise suitable groundwater. An apparent exception to this distribution is found in the neighbourhood of Paris, where sandy gypsum crystals are stated to occur in certain springs, and as quartz pseudomorphs in the *arrondissement* of Vaugirard. Gypsum crystals embodying clayey matter have been described from Bohemia and Spain.

In October, 1947, a number of shallow native-dug wells situated along the 140-mile stretch of British Somaliland coast between Berbera and Zeila were examined during a survey of water possibilities for a scheme for growing dates. One group of wells investigated is known as El Batalaleh [1] (Lat. 10° 27′ N., Long. 45° 04′ E.), about one mile east of Berbera town. Some had been recently dug and others were still digging for a small private Somali irrigation scheme, and a species of dwarf millet was growing successfully despite the extremely saline nature of the water. The wells lie about half a mile from the sea and extend over an area some 500 yards in diameter. They are dug in the most recent Raised Beach, approximately 2 metres above the present sea-level. A few hundred yards to the south the older 8-metre Raised Beach of consolidated coral rock rises steeply.

Most of the wells are of comparatively large diameter, about 10 feet, conditioned by the caving nature of the sand from 2 to 5 feet, no revetting being used.

The section thus exposed shows :—

Feet.	
0–2	Sandy clay.
–5	Unconsolidated beach sand and grit, with molluscan shells.
–9 (seen)	Beach sand as above, but largely hardened by the deposition of sandy gypsum crystals, with loose sand in the interstices.

The original loose sand consists mainly of quartz grains with subsidiary minerals and a little calcareous material from molluscan shells. It runs freely when dry, and when washed showed only slight muddiness in the water. It is thus practically a clean sand.

A rough estimation of the grain size, made on 6 oz. of the loose sand, weighed on a letter weight reading to quarter ounces, gave the following result :—

	Percentage by weight.	
	Fractions.	*Cumulative.*
Retained by sieve of 8 meshes to the inch	4	4
" " " 10 " " "	2	6
" " " 20 " " "	3	9
" " " 30 " " "	5	14
" " " 40 " " "	10	24
" " " 50 " " "	47	71
" " " 100 " " "	29	100
Passed " " 100 " " "	traces	

[1] *El* (pronounced *eil* in the R.G.S. II system) is here the Somali word meaning " water well " ; it is not the Arabic definite article.

Two rough experiments to determine the porosity gave results of 31 per cent and 33 per cent voids in the well shaken-down sand.

The crystalline gypsum has been deposited so that not only does it completely fill the voids between the grains of the undisturbed sand, but, as Dr. Campbell Smith reports below, the crystallization has actually forced the individual sand grains apart, so that these are now completely surrounded by gypsum.

The water level at 10.00 hours on 23rd October, 1947, was 7 feet below surface, but it may possibly fluctuate with the tides.

The water temperature was then measured as 84° F. (28·9° C.) in the wide open pool that was the well. Since this was freely exposed to the sun's warming by day and to radiation cooling at night, the temperature measured may not really be that of the ground water. Similar wells, but of smaller diameter, dug in this Raised Beach at other sites along the coast to the west, had water temperatures measured as ranging from 90–95° F. (32·2–35·6° C.), which may more nearly represent the normal groundwater temperature at El Batalaleh.

I made a partial analysis [1] of a water sample collected on 23rd October, 1947, with results as given in the table on the next page, which are compared with two analyses of waters that apparently also produce sandy gypsum crystals in the Tunisian Sahara, recalculated from Vatonne, 1863.

The two principal salts indicated by the El Batalaleh analysis are calcium sulphate 4460 p.p.m. and sodium chloride 2805 p.p.m.

The water is a concentrated saline groundwater, which is presumably banked against and floating upon sea water in the coastal deposits. It is not derived from sea water, but I think clearly comes from land drainage from the Dubriat range; and from the Daban area farther south, whence it flows underground through the Suria Malableh gap. In both these areas anhydrite and other gypseous strata outcrop, and water of the Biyo Gora stream near by has high chloride as well as sulphate. Flowing below the surface of the hot maritime plain the water has probably become concentrated.

[1] In the El Batalaleh water analysis, chloride was estimated by titration with N/100 silver nitrate. Sulphate was estimated volumetrically by trial and error "titration" with N/80 barium chloride acidified with hydrochloric acid (see W. A. Macfadyen, 1933, *Journ. Inst. Pet. Tech.*, xix, 681–2). Carbonate and bicarbonate were estimated by titration with N/50 sulphuric acid, using phenolphthalein and methyl orange indicators. Sp. gr. was measured by *Alfloc* hydrometer. *p*H was estimated by colour with B.D.H. Universal Indicator.

Sodium is calculated from the chloride figure; this is wholly credited to sodium, ignoring a possible small proportion of potassium. Calcium is calculated from the sulphate, carbonate, and bicarbonate figures, ignoring a probable small proportion of magnesium.

The resulting analysis, while obviously not of a high degree of precision does, however, give a useful approximation to the composition of the water.

The circumstances are thus fairly clearly defined. The crystals grew, and are probably still growing, in the voids of a bed of sand. The mother-water has a very high content of calcium sulphate and high sodium chloride, with subsidiary carbonates. The temperature is probably between about 29–35° C. The crystals are found over a vertical range of at least 4 feet, their base not having been seen exposed. They grow below the observed water level, and for a couple of feet above it, though this last part of the deposit may possibly be flooded intermittently, the water level rising owing to the influence of the ocean tides. This point requires verification.

	British Somaliland	Tunisian Sahara	
	El Batalaleh well, parts per million	Ghadamès spring, parts per million	El Oued well, parts per million
Sulphate (SO_4)	3,150	1,174	1,949
Chloride (Cl)	1,702	386	684
Carbonate (CO_3)	10	130	59
Bicarbonate (HCO_3)	112	—	—
Nitrate (NO_3)	—	tr	482
Sodium (Na)	1,103 [1]	356	379
Potassium (K)	—	11	127
Calcium (Ca)	1,353 [1]	306	746
Magnesium (Mg)	—	106	154
Silica (SiO_2)	—	6	53
Iron Oxide (Fe_2O_3)	—	5	13
Total Dissolved Solids: Calculated	7,430	2,485	4,645
" " " Weighed	7,550 [2]	2,547	4,818
Sp. Gr.	1·0068 at 60° F.	1·00231 at 15° C.	1·0043 at 15° C.
*p*H (approx.)	8·5	—	—

Geologically speaking, the crystals must be of relatively recent growth, for the 2-m. Raised Beach is of a very late date, and the crystals cannot have started growing until the present conditions of the gypseous groundwater were established after the beach was raised.

No similar crystals were observed in any of the other sixteen groups of wells examined between Berbera and Zeila, though they were not specially sought, since the El Batalaleh wells were the last to be investigated. The quality of these other well waters, fifteen of the groups being analysed,[3] was generally less saline than that of

[1] These sodium and calcium figures are calculated, not estimated.

[2] This figure is an approximation calculated from the sp. gr., and not weighed.

[3] These analyses are given in part 8 of a volume by the writer, *Water Supplies and Geology of parts of British Somaliland*, now in course of publication by the Colonial Office.

El Batalaleh, except in four cases, one of which was clearly sea water.

The crystals occur as oval lenticles, with convex faces and sharp periphery. In size they have been collected ranging from about 1·5 cm. to some 15 cm. in longer diameter. The maximum thickness is usually about one-fifth of the longer axis. A few much thicker lenses were found, up to about half the longer axis, but the edges of these are generally imperfect. There is considerable interference in the growth of one crystal by others in the apparently randomly arranged congeries. Dr. Campbell Smith did not recognize any definite twins but only irregular interpenetrating groups. The crystals vary from greyish to dull brown, according to the colour of the sand, the actual gypsum being clear and colourless. Deposition of the gypsum has taken place quite irrespective of the arrangement of the clastic material, so that the crystal faces are rough with projecting sand grains, pebbles, and shells (Plate XIX).

Dr. W. Campbell Smith has very kindly given the following description :—

The crystals are similar in habit to those which form the well known " desert roses " found in the sands of the Sahara.

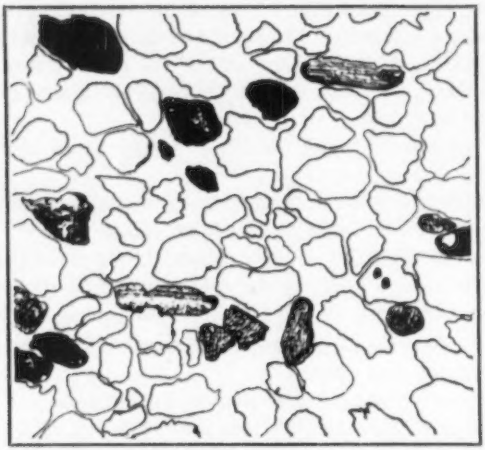
The lenses are flattened roughly parallel to the plane (101) and the convex surfaces are built up by extremely small steps which are combinations of forms in the zone [100,001] such as (101), (103), ($\bar{1}$03), and ($\bar{2}$03) (Dana's indices), together with forms such as (111) and others in the zone [010,111].

Some of the crystals are nearly circular, but most are oval in outline. The long edges of these oval sections are roughly parallel to the good cleavage (010) which appears as breaks on two opposite edges. The terminal curved boundaries are formed by oscillation of the faces m(110) with b(010). A bright sheen is reflected from the 010 cleavage surface, and seen in certain directions the sheen can be caught from the small steps on the drusy curved surfaces of the lenses.

The sand consists chiefly of rounded and subangular grains of quartz, together with plagioclase feldspar, hornblende, garnet, and other minerals derivable from granitic or gneissic country rock, and grains of turbid calcite, chiefly fragments of shells. The average grain-size is near 0·25 mm., with grains up to 0·5 mm. in diameter.

A very interesting fact is that in the gypsum crystals the sand grains are no longer in contact (Fig. 1) as they must have been in the dry sand. Before the growth of the gypsum began each grain would be surrounded by a pellicle of the gypseous water. As crystallization took place the growing crystal moved the sand grains apart, each grain moving away from its neighbours until the average distance between grains is of the order of 0·1–0·15 mm.

The result of this is an expansion of the volume occupied by sand and gypsum that was once occupied by sand alone. The porosity of the sand is estimated by Macfadyen (above) as about 32 per cent. The volume per cent of gypsum in one of the lenticular crystals is about 39 per cent, thus considerably exceeding the porosity of the sand. This was a rough determination based on the density of the sand-filled crystals and assuming the sand to be all quartz. A better determination was made by Mr. D. I. Bothwell, of the Department of Mineralogy, British Museum (Natural History), by dissolving the gypsum in hot water and weighing the dried insoluble residue. This



TEXT-FIG. 1.—Thin section of sandy gypsum crystal showing separated grains of quartz, shell fragments, etc., set in clear gypsum. × 25.

gave 65·2 per cent by weight of sand, which is nearly equivalent to 62 per cent by volume, and 38 per cent by volume of gypsum.

Specimens have deen deposited in the Department of Mineralogy, British Museum (Natural History) (Regd. Nos. BM. 1949, 393–7); and in the Sedgwick Museum, Cambridge.

Dr. Campbell Smith remarks that lenticular crystals of gypsum are known from many localities. Rather thick lenticular crystals have been found at Shotover Hill, near Oxford, and several types occur in beds in the Paris basin. Their form was worked out by Lacroix (1897, pp. 209–210), who also briefly described the " roses du désert " from the Algerian Sahara characterized by strong development of (111) with (010), elongated parallel to [010, 111] and rarely terminated by definite faces m(110). They sometimes reach several decimetres in

greatest diameter. Whitlock has figured these and other so-called desert roses (1930).

Sand-filled gypsum crystals of quite different habit are found in Lake Kara-chungul, Uralsk Province, U.S.S.R., at the north end of the Caspian Sea. Specimens are preserved in the Department of Mineralogy, British Museum (Natural History), Regd. No. 1913, 180. There is apparently no published description of them. The lake is in gypsum deposits of Permian age, surrounded by sand derived from the Cretaceous sandstones round the lake. In spring, when the lake-level rises, the saturated gypseous water seeps into the sand and crystallizes as gypsum. Groups of gypsum crystals are revealed when wind blows away the sand in dry weather. These crystals are large and rough. The form consists of hollow faces representing the pair of faces 111 and $1\bar{1}1$ and poorly developed faces in the zone [100, 010] with drusy smaller 010 faces.

Comparison with Previous Records

The fullest record and description of sandy crystals of calcite and of baryte that I have found is that of Delkeskamp (1903), though he gives little about gypsum. Other good records and description of sandy crystals are given by Lacroix (1901), and of sandy gypsum crystals by Doss (1897) ; and records and good photographs by Whitlock (1930). Some useful notes are given by Kaiser and Neumaier (1932). Vatonne (1863) gives most detail of the occurrence of his gypsum crystals, and analyses of the waters.

The sandy gypsum crystals of which I have found record come from the following localities :—

Sahara Desert of Algeria and Tunisia : Ouargla (Ville) ; Souf, Bir Ghardaia, Tougourt, El Oued, Ghadamès (Vatonne, 1863) ; Biskra (Whitlock, 1930).

Caspian Region : Transcaspia, Repetek District, between Merv and the River Amu Darya (Oxus) (Eremyeev, 1895) ; and between Peski and Karaul Kuyu along the railway (Walther, 1900) ; Transcaspia, at Eslam-Kuyu (Samoilova, 1913). Bogdo Hills, near Lake Baskuntschak, Astrakhan Steppe (Doss, 1897). Kara-chungul Lake, Uralsk Province, north of the Caspian Sea (specimens in the British Museum (Nat. Hist.)).

Bolivia, at Carcote (Pöhlmann, 1892).

Gobi Desert, Inner Mongolia, Sahara Murum region (Whitlock, 1930).

South-West Africa : Walvis Bay (Wulf, 1887) ; and the Namib Desert (Kaiser, 1926 ; Kaiser and Neumaier, 1932).

In addition, from more temperate climate, they are recorded from

undesignated springs in the Paris district (Delkeskamp, 1903), and as quartz pseudomorphs from the Paris *arrondissement* of Vaugirard (Whitlock, 1930).

Size of the Crystals

Doss gives the size of the Bogdo Hills specimens as up to 12 × 16 cm.

Vatonne states that those from Ghadamès are much larger than the Tougourt and Oued Souf specimens, but unfortunately he gives no dimensions. "*Le gypse sableux, en enormes cristaux accolés se groupe en masses présentant les formes générales les plus bizarres*" (1863, p. 275). Lacroix (1910) states that these Ghadamès specimens may reach several decimetres in greater diameter.

The Berbera examples range up to about 15 cm. in greatest diameter. When extracted from the wells in large masses, which, however, is rarely done by the Somali well diggers, congeries of crystals are seen which are comparable with the description of those from the Sahara.

Walther (1898) states that the crystals in the Repetek district are the length of a finger (i.e. some 8 cm.), and he figures one, of elongate form, from the Karakum dunes (1900, fig. 49).

Sand Content and Orientation

The percentage of sand and other foreign matter recorded ranges generally, according to the published data, from 38·55 to 65·2 per cent, namely: Bogdo Hills, Astrakhan, 38·55, 46·40, and 48·58 per cent (presumed by weight); Carcote, Bolivia, up to 50 per cent; Sahara desert 47 to 62·1 per cent by weight. These compare with the Berbera figure of 65·2 per cent by weight, equivalent to 62 per cent by volume. Enclosed in the Walvis Bay examples Wulf found a few diatoms.

The crystal figured by Doss from the Bogdo Hills, Astrakhan, had a central zone of clear gypsum, devoid of sand.

In the Namib desert the crystals are described as always containing a large quantity of sand and other detritus (*Schutt*), but in some this is definitely oriented, and the crystals show sand-rich and sand-poor zones. The outermost zone of good crystals is usually completely clear and free of sand.

In connection with this zoning, and with the observation that the sand grains in the Berbera crystals (which show no sign of zoning) are completely separated by gypsum, Samoilova (1913) figures a thin section of one of her Transcaspian crystals which shows the sand grains irregularly dispersed in the gypsum, some being in contact with each other, while others appear widely separated.

It may be added that gypsum crystals have been grown experi-

mentally by Maschke and Vater (1900) from solutions containing various addition agents, including eosin, and that this colouring matter was found to be dispersed " molecularly " through the crystals that were produced. Katzer (1891) has recorded gypsum crystals from a vein in Silurian sediments at Alt Straschnitz near Prague which embodied 16 per cent of foreign matter (shale particles) ; and from Cretaceous marls near Libochwitz, where crystals up to 3 cm. in greatest diameter contained 4·68 per cent of clay.

Garrido (1945) described from a Miocene gypsum deposit at Guardamar de Segura, province of Alicante, Spain, crystals sometimes exceeding 7 cm. in length and usually twinned " *en fer de lance* ", which contained an unspecified quantity of clay which had been deposited in straight lines (*sic*) marking successive growth stages. While his figure shows this in section, the clay had presumably been deposited in planes rather than in lines. The innermost part of the crystals was nearly pure, the impurities increasing towards the exterior.

Geological Age and Field Relations

In cases where the age is recorded or can be deduced, a Recent date is generally indicated for typical sandy gypsum crystals, as in the dunes of the Sahara (in part at least, for other specimens are recorded as dug from wells, or occurring in conditions which resemble the bed of a dried up lake) ; in the dunes of the Gobi desert ; in the Namib desert ; and in Transcaspia. The Berbera crystals are also of sub-Recent to Recent date.

The Walvis Bay site in South-West Africa appears closely to parallel that of Berbera, for the crystals are found in low-lying sands close to the sea coast.

Walther (1900) states that sandy gypsum crystals are seen as curios on many of the Transcaspian Railway stations, and they are offered for sale at Repetek station. In the Samarkand Museum he saw a group of these crystals, some 80 cm. in diameter. The railway between Peski and Karaul Kuyu traverses a depression in the sand sea, 100 km. long by 30 km. wide, and there are other large depressions near by. Lying on the ground surface in these depressions are found sandy gypsum crystals, and they occur also at depths of 20 cm. and below in the dune sands. Walther states that A. Palezky cleared all the crystals away from an area for a garden of desert plants, but found that after a year a new crop of the crystals had grown on the surface there by capillary action.

Temperature of Groundwater

I have found this recorded only by Vatonne from the Sahara. The temperature of Ghadamès spring was 29° C., and that of El Oued

wells 22·8° C. This compares with the 29–35° C. of the El Batalaleh, Berbera, wells.

Water Analyses

Water analyses are given in detail only by Vatonne for various of the Sahara sites, and two have been recalculated to compare with that of El Batalaleh water, as shown above. The El Batalaleh water appears to be almost exactly three times as concentrated as the Ghadamès water, and rather less than twice that of El Oued. This may be of significance, since Lacroix (1898, p. 39) states that only lenticular crystals are produced in very concentrated waters. It is not clear, however, whether he had in mind naturally occurring waters or experimental solutions in the laboratory. If the former, then the El Batalaleh water is highly concentrated ; but if the latter then it has little sodium chloride, for example, compared with the massive additions of that salt in various experimental solutions that have been used.

In general the three waters whose analyses are given above appear comparable, though the proportion of chloride is higher at El Batalaleh. Nitrate, which was not estimated in the El Batalaleh sample, and is negligible in that from Ghadamès, is exceedingly high at El Oued, as is sometimes found elsewhere in desert ground waters.

Sulphate is by far the highest individual ion in all three.

Deicha (1943) claims that a high concentration of sodium chloride in the mother liquor is the factor producing curved faces in gypsum crystals, and such curved faces are present in those now described. But whether the sodium chloride content of the El Batalaleh water would fall within Deicha's range of high concentration seems very doubtful.

The solubility of gypsum in water at different temperatures and with increasing additions of sodium chloride has been studied by various chemists.[1] Their results show that, though the maximum solubility in pure water lies between 30–40° C., when it is about 2·1 gm./litre (calculated as the anhydrous sulphate), temperature change alone has no large effect. But the addition of much sodium chloride has a large effect, the maximum solubility being found with about 130–150 gm./litre NaCl, when it is raised to about 7·5 gm./litre of the anhydrous sulphate, equivalent to 9·2 gm./litre of gypsum. Further additions then decrease the solubility.

The El Batalaleh water does not appear to agree well with these

[1] For example, Cameron, F. K., 1901, *Journ. Phys. Chem.*, v, pp. 556–576 ; Hulett and Allen, 1902, *Journ. Amer. Chem. Soc.*, xxiv, p. 667 ; d'Anselme, A., 1903, *Bull. Soc. chim.*, Paris, 3 ser., xxix, pp. 372–4 ; Le Chatelier, H., 1916, *C. R. Ac. Sci.*, Paris, clxii, pp. 931–2.

findings, for a content of 4·46 gm./litre of dissolved $CaSO_4$ as calculated would call for a NaCl content of *circa* 25–30 gm./litre, while in fact only 2·8 gm./litre was found. This suggests that either the water contains some proportion of a sulphate that has not been recognized in the analysis, and wrongly calculated to calcium; or that the other salts in the water have increased still further the solubility of $CaSO_4$ in it. The facts can only be established by a complete analysis of the water.

There seems no doubt, however, that there is a comparatively large amount of dissolved calcium sulphate in the water, and this has been a major factor in the production of the sandy gypsum crystals, while the various associated salts have probably influenced the reactions and solubilities involved.

I am greatly indebted to Dr. W. Campbell Smith for his crystallographic description of the specimens, printed above, and his other notes; and for his general encouragement in the preparation of this paper. He also kindly arranged for the illustrations, and for Mr. Bothwell to estimate the sand content of a crystal.

I have to thank Mr. Maurice Black for a reference to earlier work.

LIST OF WORKS TO WHICH REFERENCE IS MADE

DEICHA, G., 1943. Genèse et facies du gypse. *Bull. Soc. Franc. Minér.*, lxvi. 153–160.

DELKESKAMP, R., 1903. Über die Krystallisationsfähigkeit von Kalkspat, Schwerspat, und Gyps bei ungewöhnlich grosser Menge eingeschlossenen Quartzsandes. *Zeit. f. Naturwiss.* (Stuttgart), 1902 (1903), lxxv, 185–208.

DOSS, B., 1897. Ueber sandhaltige Gypskristalle vom Bogdo-Berge in der Astrachan'schen Steppe. *Zeit. deutsch. geol. Ges.*, xlix, 143–151.

EREMYEEV, P. V. (= Jeremejeff, Ieremief), 1895. Sur les concrétions de cristaux de gypse, trouvé en Transcaspie, dans un " barkhane ". *Bull. Ac. Imp. Sci. St. Petersbourg*, V ser., iii, lxii–lxiii. (In Russian, no summary.)

GARRIDO, J., 1945. Sur des cristaux de gypse présentant des " fantomes " de croissance. *Bol. Soc. Geol. Portugal*, iv, 213–4.

KAISER, E., 1926. *Die Diamantenwüste Südwest-Afrikas*, 4to, Berlin, ii, 129–130.

—— and NEUMAIER, F., 1932. Sand-Steinsalz-Kristallskelette aus der Namib Südwestafrikas. *Centralbl. Min. Geol. Pal.*, 1932 A, 177–188.

KATZER, F., 1891. Beiträge zur Mineralogie Böhmens. 8.—Gyps von Alt-Straschnitz und Libochwitz. *Tschermak's Min. Pet. Mitth.*, N.F., xii, 423–8.

LACROIX, A., 1897. Le Gypse de Paris et les minéraux qui l'accompagnent. *Nouv. Arch. Mus. d'Hist. Nat.* (Paris), ser. 3, ix, 201–294 (see pp. 209–210).

—— 1898. Les formes du gypse des environs de Paris. *Bull. Soc. franc. Minér.*, xxi, 39–43.

—— 1901. *Minéralogie de la France et de ses Colonies*, iii, 517.

—— 1910. *Minéralogie de la France et de ses Colonies*, iv, 187.

MASCHKE, O., and VATER, H., 1900. Mikroskopische Studien über die Krystallisation des Gypses. *Zeit. Kryst. Min.*, xxxiii, 57–71.

PÖHLMANN, R., 1892. Mineralogische Mittheilungen. Gypskrystalle, reich an Beimengungen eines feinen Sandes, von Carcote in Bolivia. *Verh. deutsch. Wiss. Ver. Santiago* (Chile), ii, 238–9.

SAMOILOVA, Y. V. (= Samojloff), 1913. Gypses poïkilitiques d'Islam-Kuju (province Transcaspienne). *Bull. Ac. Sci. St. Petersbourg*, 6 ser., vii, 783–7. (In Russian, no summary.)

VATONNE, F., 1863. Études sur les terrains et sur les eaux des pays traversés par la mission, 203–313. *In* M. M. Mircher : *Mission de Ghadamès*, 8vo, Alger.

WALTHER, J., 1898. (No title.) *Zeit. deutsch. geol. Ges.*, Bd. 50, Verhandl. der Ges., pp. 2–3.

—— 1900. *Das Gesetz der Wüstenbildung in Gegenwart und Vorzeit*, 129–130, 8vo, Berlin.

WHITLOCK, H. P., 1930. Desert Roses. *Natural History* (New York), 1929 (1930), xxx, 421–5.

WULF, H., 1887. Beitrag zur Petrographie des Hererolandes in Südwest-Afrika. *Tschermak's Min. Pet. Mitth.*, N.F., viii, 193–238. (See p. 237.)

EXPLANATION OF PLATE

Sandy gypsum crystals from Berbera, British Somaliland ; B.M. Regd. No. 1949, 394 ; Approximately actual size.

SANDY GYPSUM CRYSTALS FROM BERBERA, APPROX. NATURAL SIZE.

Occurrence of Nepheline-Monzonite and Allied Types in the Cape Verde Archipelago

By Gerald M. Part

Abstract

An account is given of nepheline-monzonites and essexites from S. Vicente and S. Tiago in the Cape Verde Archipelago.

THOUGH the type is probably more common than has been hitherto recognized, published descriptions of nepheline-monzonite are sufficiently rare to merit this record of certain specimens from the Cape Verde Archipelago which are included in the collections of the British Museum (Natural History) and of the Department of Mineralogy and Petrology, Cambridge.

In his monograph on the geology of the islands, Bebiano (1932) records a number of "monzonitic syenites" and "nepheline-monzonites" from S. Vicente, Sal, Boa Vista, and Maio. Most of these are described as micro-crystalline aggregates of orthoclase and albite with nepheline, aegirine-augite, barkevikitic hornblende, and the usual accessories—sphene, apatite, and magnetite. Some (86.BV) have porphyritic feldspars, others are more basic with andesine and even labradorite. A rock from Maio is described as a "Kentallenite".

The British Museum specimens (W. Child Collection B.M. 1915/130) come from S. Vicente and S. Tiago. In the first-named island a plug of nepheline-syenite grading into nepheline-monzonite which occurs at Pedras Brancas, south-west of Mindello, has been described by several authors and full petrological details with analyses have been given by Mario de Jesus (in Bebiano, 1932) and Ermert (1936). Child's specimens are not particularly fresh and present no new features, but at distances of 2–4 k.m. south-east of Pedras Brancas are other small intrusions of nepheline-monzonite, nepheline-monzonite porphyry, and essexite, of which we have several specimens. Some of these are thermally metamorphosed and show varying degrees of granulitization, recrystallization of feldspars, and much development of biotite.

A nepheline-monzonite (B.M. 1915/130/689), 2·8 km. S. by W. of Morro Branca, is composed of large idiomorphic titan-augite, smaller partly interstitial brown hornblende, biotite, apatite prisms, and irregular ilmenite and titaniferous magnetite in a base consisting partly of a plexus of small plagioclase prisms enclosed in plates of turbid peocilitic orthoclase and partly of turbid interstitial nepheline (Text-fig. 2.).

A rock in the Cambridge collection (25223) labelled S. Vicente is a nepheline-monzonite porphyry. Its original mode was approximately perthite 42 per cent, plagioclase 15, nepheline 18, barkevikite

9, augite 10, biotite 1, ores 5, but both feldspars and nepheline are in poor condition and much clouded by analcite and cancrinite. The long euhedral hornblendes (2–3 mm.) and the shorter and stouter titan-augites give this rock a striking appearance under the microscope. It may be compared with very similar rocks from Tahiti.

S. Tiago—a group of boulders from the valley of the Ribeira S. Jorge, 5 km. N. of Praia, comes from an intrusion not recorded by Bebiano. B.M. 1915/130/271 is a handsome pale grey nepheline-monzonite of medium grain speckled with lustrous black prisms of hornblende up to 1 cm. in length. The mode is perthite 65 per cent, plagioclase 4·7,

TEXT-FIG. 1.—Nepheline-monzonite, R. S. Jorge, 5 km. N. of Praia, S. Tiago, C. Verde Is. (BM. 1915/130/271). × 20.

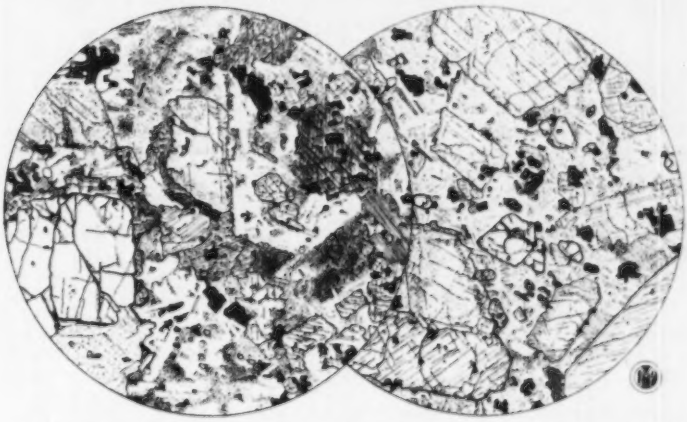
TEXT-FIG. 2.—Nepheline-monzonite, 2·8 km. S. by W. of Morro Branca, S. Vicente, C. Verde Is. (BM. 1915/130/689). × 20.

nepheline 11·4, hornblende 7·7, aegirine-augite 4·4, sphene 4·2, apatite 0·9, magnetite 1·7. The perthite occurs in hypidiomorphic prisms up to 6–7 mm. in length, frequently moulded on cores of deeply corroded plagioclase (zoned from An_{60-25}). These cores, which exhibit a tendency to stellate grouping (Text-fig. 1), are surrounded by reaction rims of granular perthite and nepheline. The nepheline also occurs interstitially between the larger perthites and much of it is clouded by analcite and cancrinite; some analcite may be primary. Aegirine-augite reaches a size of 1 mm. The mineral is euhedral, moderately pleochroic in shades of grass-green and greenish yellow (Z/c 57°), the larger crystals having either a paler green aegirine-augite (Z/c 52°) or a pale violet titan-augite (Z/c 47°) in their interior. Hornblende builds long prismatic crystals of good shape, strongly pleochroic (X straw

yellow < Y golden brown < Z deep chestnut brown) with Z/c small, not exceeding 5–7°. Most crystals have patches or borders of blue-green arfvedsonite almost uniaxial (–) in character. In this connection, Bebiano mentions a nepheline-syenite from Boa Vista with blue-green hastingsite.

B.M. 1915/130/265 is a slightly darker and finer-grained rock containing a " basic inclusion " rich in brown hornblende and sphene.

The basic member of this suite is an essexite (B.M. 1915/130/273), composed of orthoclase 10·0 per cent, plagioclase (zoned An_{65-30}) 14·7, nepheline 6·9, analcite 3·1, titan-augite 36·0, brown hornblende



TEXT-FIG. 3.—Essexite, R. S. Jorge, 5 km. N. of Praia, S. Tiago, C. Verde Is. (BM. 1915/130/273). × 20.

TEXT-FIG. 4.—Essexite-porphyry, Praia, S. Tiago, C. Verde Is. (BM. 1920/668/18). × 30.

9·1, biotite 4·6, olivine 3·3, apatite 3·1, and magnetite, probably titaniferous, 9·2. The titan-augite occurs in phenocrysts up to 1 cm. in size, the larger ones fairly well formed, the smaller averaging about 1 mm., having very ragged margins filled with inclusions of hornblende and biotite. In addition to entering into these fringing intergrowths the hornblende also forms ragged plates enveloping the plagioclase which occurs in a plexus of laths (zoned An_{65-30}) with interstitial patches of analcite, nepheline and orthoclase (Text-fig. 3).

This essexite is cut by pegmatite veins of " syenitic "-type, composed of a coarse mixture—in places a graphic intergrowth—of perthite and nepheline. The coloured constituents are long narrow plates of biotite with a few, rare titan-augites which are obviously " strays " stoped off from the essexite (1915/130/271a).

The Collections include several examples of essexite-porphyry essentially akin to the foregoing, such as B.M. 1915/130/303 Rio Brava, S. Nicolao, B.M. 1920/668/18, Praia, S. Tiago (Text-fig. 4), and 33913 Praia, S. Tiago. Typically all have abundant titan-augite in large, usually ragged, phenocrysts, less abundant olivine and much

TABLE I.

	271	A	B	C	146.S	341	273	D
SiO_2	53·65	54·97	51·34	54·42	53·18	52·08	44·55	43·06
TiO_2	1·30	0·64	1·48	1·31	1·80	0·61	3·24	4·81
Al_2O_3	20·58	20·06	22·18	19·23	19·62	20·62	11·62	10·07
Fe_2O_3	1·00	3·43	2·20	2·93	3·39	3·42	5·53	8·43
FeO	1·36	1·25	2·35	2·22	3·57	2·28	5·20	6·04
MnO	0·08	0·21	0·11	—	0·04	—	0·18	—
CaO	4·50	2·60	4·58	5·04	4·84	4·32	13·16	12·72
MgO	1·28	0·43	0·82	0·78	1·40	0·21	9·40	7·99
Na_2O	6·34	8·27	7·56	6·41	7·45	8·61	2·19	3·12
K_2O	5·08	5·14	4·42	5·73	3·84	3·91	1·86	2·28
P_2O_5	0·30	0·20	0·17	0·24	0·42	0·15	0·48	0·66
CO_2	0·24	0·99	0·34	0·88	tr	1·01	0·08	—
Cl	—	—	—	0·06	0·09	0·08	—	—
SO_3	—	—	—	0·17	tr	—	—	—
H_2O −	0·27	—	0·20	0·34	0·20	0·29	0·15	0·25
H_2O +	3·30	2·17	1·70	0·59	0·67	2·47	1·31	0·29
	99·28	100·36	100·08	100·18	100·51	100·12	98·95	100·12
Norms								
or	30·0	30·0	26·4	34·9	22·9	23·3	11·2	13·5
ab	29·3	37·0	31·2	33·0	34·5	34·0	9·4	14·3
an	12·8	3·9	14·7	6·3	8·8	5·9	16·4	14·2
ne	13·6	17·4	18·3	10·8	15·1	21·2	4·7	6·9
wo	—	—	—	—	—	2·1	—	9·1
di	4·7	1·8	4·5	2·4	9·2	1·8	34·6	21·6
ol	0·7	0·2	0·2	0·6	4·6	—	5·0	hm. 6·3
mt	0·9	2·8	1·4	3·5	4·9	4·9	7·9	3·5
il	2·4	1·2	2·7	2·4	3·4	1·2	6·2	9·3
ap	0·7	0·4	0·3	0·7	1·1	0·3	1·0	1·7
cc	0·7	2·2	0·8	2·0	—	2·8	0·2	—

271. Nepheline-monzonite, R. S. Jorge, Praia, S. Tiago, C. Verde Is. (Geochemical Laboratories). I′. ′6. 2. ′4. [BM. 1915/130/271.]

A. Nepheline-syenite, Pedras Brancas, S. Vicente, C. Verde Is. (Schluntz). I′. 6. 1′. 4. (Ermert, 1936.)

B. Nepheline-monzonite, Papenoo Valley, Tahiti. I. (5) 6. 2. 4. (Lacroix, 1927.)

C. Nepheline-monzonite, Corporation Qy., Mt. Royal, Montreal, Quebec (Raoult). I. (5) 6. ′2. 3′. (Lacroix, 1922.)

146.S. Nepheline-monzonite, 2 km. S., 25° E., of Palmeira, Sal, C. Verde Is. (M. de Jesus). II. (5) 6. ′2. 4. (Bebiano, 1932.)

341. Tahitite, Bekotapo, Madagascar. I′. 6. 1′. 4. (Lacroix, 1923.)

273. Essexite, R. S. Jorge, Praia, S. Tiago, C. Verde Is. (Geochemical Laboratories). III. 5. 3. (3) 4. [BM. 1915/130/273.]

D. Monzonitic Shönkinite, 1,300 m. S., 78° W., of church of Monchique (Sitio do Borrôca), Sierra de Monchique, Portugal. III. (5) 6. (2) 3. ′4. (Pereira de Sousa, 1926.)

titano-magnetite with minor amounts of biotite and brown hornblende. The ground-mass is a plexus of plagioclase laths (An_{60-22}) in a base composed of more or less equal parts of orthoclase and nepheline.

In several passages Bebiano records augite " alterada em anfiboles castanhas ", obviously referring to the zone of ragged hornblende (and biotite) inclusions frequently seen in the marginal parts of the pyroxene phenocrysts, but in the present writer's opinion the term " alteration to hornblende " does not give quite the right picture of this phenomenon, which is rather the mineralogical expression of the changing conditions of chemical equilibrium during the later stages of crystallization, when increasing concentration of water and alkalies promotes the

TABLE II.—MODES

	271	265	265 Basic Patch	A	25223	273
Orthoclase	65·0	57·0	32·2	57·8	42	10·0
Plagioclase	4·7	2·7	6·3		15	14·7
Nepheline	11·4	15·1	8·0	20·0	18	6·9
Analcite	—	4·3	3·6	7·2	—	3·1
Augite	4·4	4·2	4·8		10	36·0
Hornblende	7·7	7·7	34·1		9	9·1
Olivine	—	—	—		—	3·3
Biotite	—	—	—	15·0	1	4·6
Sphene	4·2	3·8	5·0		—	—
Apatite	0·9	1·0	2·4		—	3·1
Ores.	1·7	4·2	3·6		5	9·2

A Nepheline-syenite, Pedras Brancas, S. Vicente, C. Verde Is. (Ermert 2). 22523 Nepheline-monzonite porphyry, S. Vicente, C. Verde Is. Others R. S. Jorge, 5 km. N. of Praia, S. Tiago, C. Verde Is. (Except in [273] most of the orthoclase is perthitic.)

formation of hydroxyl-bearing amphibole and mica in preference to the " dry " pyroxenes. These particular rocks show the early onset of such conditions while the margins of the titan-augite phenocrysts were still growing.

Chemically these rocks can best be matched by certain nepheline-monzonites and monzonitic nepheline-syenites as shown in Table 1, which contains the analyses of (271) and (273), together with comparable figures from Bebiano and other sources. Mineralogically, the bulk of their plagioclase, as shown in the norms, appears in the perthite. It must be pointed out that all these Cape Verde Is. occurrences appear to be vent-fillings and none are genuine deep-seated plutonic types. The corresponding extrusive phase includes a great variety of phonolites in some of which, chemically comparable to the vent-fillings, much of the potash appears in the nepheline (Part, 1950, p. 44). In Table II are the modes of certain of the rocks described

above. Attention may be drawn to the analysis of Tahitite (Lacroix, 341). The presence of rocks of this type in the British Museum Collection was first brought to my notice by Dr. Campbell Smith and it is probable that others remain to be recognized in the Archipelago, particularly as there are other resemblances between the rocks of these islands and of Tahiti (Part, 1950, p. 46).

I am indebted to the Trustees of the British Museum (Nat. Hist.) and to the Keeper of Minerals (Dr. Campbell Smith), also to Professor Tilley, of Cambridge, for the opportunity to study this material. The cost of the two chemical analyses for which I have to thank Mr. H. B. Milner, of Geochemical Laboratories, was covered by a grant from the Government Grants Committee of the Royal Society.

REFERENCES

Bebiano, J. B., 1932. A. geologia do Arquipelago de Cabo Verde. *Serv. Géol. Portugal.*

Ermert, H., 1936. Ein beitrage zur Kenntnis der gesteine de Kapverdischen Insein Sao Vicente und Sal. *Chemie der Erde*, 10, 155–186.

Lacroix, A., 1922. *Mineralogie de Madagascar*, ii.

—— 1923. Ibid., iii, 182.

—— 1927. *Mém. Acad. Sci. de l'Inst. France*, 59.

Part, G. M., 1950. Volcanic rocks from the Cape Verde Islands. *Bull. Brit. Mus. (Nat. Hist.) Mineralogy*, i, 2.

Pereira de Sousa, F. L., 1926. La Serra de Monchique. *Bull. Soc. Géol. France*, 4, xxvi, 321–350.

Note on Lineation, Boudinage, and Recumbent-folds in the Struan Flags (Moine), near Dalnacardoch, Perthshire

By DONALD B. MCINTYRE

ABSTRACT

Present knowledge of the tectonics of the Struan area is summarized. Recumbent-folds and incipient boudinage are recorded in the Struan Flags. The different types of lineation present are described; it is pointed out that all types present are mutually parallel. Simple kinematic analysis of an exposure north-west of Dalnacardoch, demonstrates that the lineations coincide more or less closely with the axis of rolling; they are therefore *b*-lineations. The need for further field-work is stressed, and the type of data required is indicated.

THE exposure described is in a roadside quarry nearly three miles north-west of Dalnacardoch, in the valley of the Garry. The surrounding region was described in detail by George Barrow (1904) from whose paper the following description is quoted (p. 401): "Since the days of McCulloch, the River Garry above Struan has been famous for the sections of flag-like rocks which are exposed in its bed and banks, from Struan, almost without interruption, to the summit of the Highland Railway. Its most striking feature is the extraordinary simulation of a normal sequence of enormous thickness, the dip being apparently persistent in one direction (the south-east), at an angle of from 20° to 30°."

According to Barrow the very large outcrop of the Central Highland Granulite (Struan Flags) is due to folding of the rock upon itself, without infolds of other material; it is "really the outcrop of a great sheet formed by the repeated folding of a bed on itself, after the manner of the bellows of a concertina when shut up. This concertina-structure was produced by the first and greatest folding of the Highland rocks, and to it is due the erroneous idea that the latter were of great thickness originally" (1904, p. 443). For Barrow, the grand-scale style was characterized by superposed concertinas. This hypothesis has not been accepted by later workers (see Bailey, 1925, pp. 673–4).

Folds, on any scale, have rarely been noticed in the Struan Flags. However, in the exposures, then newly opened, in the cuttings on the Highland Railway, J. S. Grant Wilson observed folding: "The extreme freshness of the section enables us to see that there are present a series of small folds or buckles, which consist of two parts—first, a longer limb, rising comparatively slowly; and second, a short limb, in which an abrupt fall takes place and counteracts the slow rise. The longer limb is the part of the structure seen everywhere over the whole

area, and this can be recognised at least ten times as often as the shorter falling limb. The longer limb, so easily seen, is the part of the structure which gives the mistaken notion of a persistent dip. If now we proceed to examine the other side of the cutting, which has been exposed to weathering for years, it is by no means easy to see the structure referred to. In the bed of the Garry it is still more difficult " (1905, pp. 67–8). Hitherto, no recumbent-folds have been found in the Struan Flags.

It cannot be assumed *a priori* that, in a region of apparently uniform dip, the strike of the folds necessarily coincides with the general strike of the beds. Normally, fold-strike coincides with the general strike only if the fold-axis (for definitions see McIntyre, 1950) be horizontal or if the beds be vertical. Structures characterized by flat recumbent-folds empiled one on top of the other, often have a general strike nearly at right-angles to the true axial-direction. Examples of this apparent anomaly, which is merely an expression of the geometric form, are common in the Alps, in Scandinavia, and in the Scottish Highlands. It is thus obvious that in a region such as the one discussed, determination of the axial-plunge of the major structures is necessary before any discussion of the general structure is possible.

There are a number of ways by which the axial-plunge of the grand-scale elements may be determined in a segment of an orogenic belt.

(i) By study of the plunge of intermediate-scale structures. In the Struan Flags, as we have remarked above, small-scale folds have rarely been observed. It is therefore clear that one cannot be optimistic about the use of this method in the region referred to.

(ii) By geometric construction from the orientation of the bedding. This method can be adopted only when the dips are sufficiently diverse, and therefore it would not seem to have application to the Struan Flags. However, vertical bedding is shown at several localities on the published map. Further field-work, with determination of all dips differing from the prevalent dip of the flags, may yield sufficient data to enable this method to be applied.

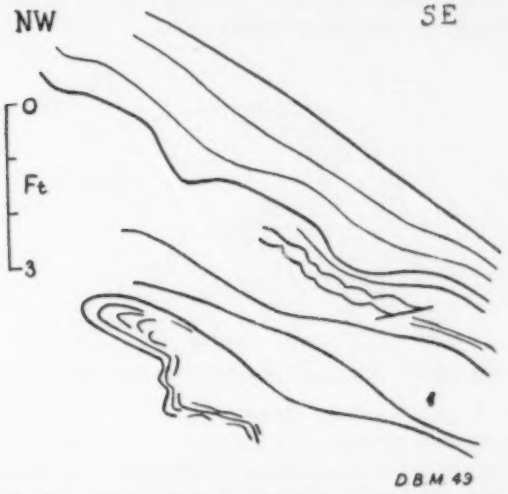
(iii) By stratum contouring the mappable contacts. This method requires reliable mapping and a considerable degree of topographic relief before it can yield more than very approximate results. The relief in the valley of the Garry is hardly sufficient for this, and no mappable contacts have yet been found within the Struan Flags.

(iv) By use of linear structures parallel to the plunge of the fold-axis. This method would seem to be the most suitable for the region considered and it will be discussed more fully. Nevertheless, so far as is possible, all methods should be employed.

Whether lineation can be used for the determination of axial-plunge resolves itself into two questions :—

1. Is lineation present in the area, and
2. Is this lineation parallel to the axis ?

The answer to the first question can be found in the published literature. Describing the more micaceous gneiss of the Struan area, Barrow stated (1904, p. 408) that " the gneiss is at times ' rodded ',[1] that is, the micas are all elongated in a definite direction ". This structure is clearly linear. Moreover, a further possible linear structure is suggested by Barrow's description (1904, p. 403) of cleavage in the " highly-micaceous bands, originally more of the nature of shales, that occur at



TEXT-FIG. 1.—General profile of exposure near Dalnacardoch.

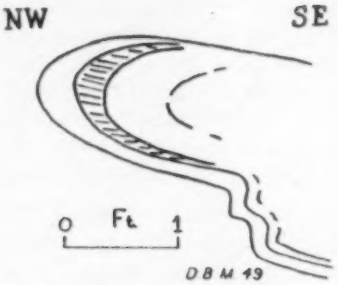
intervals throughout the whole of the Struan section." " This cleavage ", he wrote, " obviously took place prior to any crystallization, and, as a rule, it ends abruptly against the colour-banded rocks which, from their present composition, must have been of a more sandy nature originally, and would not cleave." Intersection of this cleavage with the bedding gives a linear structure. Attention has recently been drawn to the relation between such lineation and fold-plunge (Gilbert Wilson, 1946).

Plate III of the memoir illustrates " the remarkable ' water-pipe ' structure in the Moine gneisses west of Cluns, in the Garry ".

[1] This is not the usual use of the term.

Describing this structure in one sentence (1905, p. 68), Grant Wilson explained it as being due to the outcrop of the fold-hinge ; that is, he interpreted this linear structure as oriented parallel to the fold-axis. However, this structure is not of common occurrence in the flags.

The section exposed in the quarry north-west of Dalnacardoch affords valuable evidence as to the relations between lineation and fold-axes in the Struan Flags. It is therefore described in detail. The exposure makes a three-dimensional examination of the structures possible. Fig. 1 represents the profile (perpendicular to the fold-axis) of part of the quarry face. It will be seen that both boudinage and recumbent-folding are present. Details of these are shown in figs. 2 and 3. The axis of the incipient boudins coincides with that of the fold-system. All structures maintain nearly constant profiles for many yards measured in the axial-direction.



TEXT-FIG. 2.—Detail of recumbent-fold from Text-fig. 1.

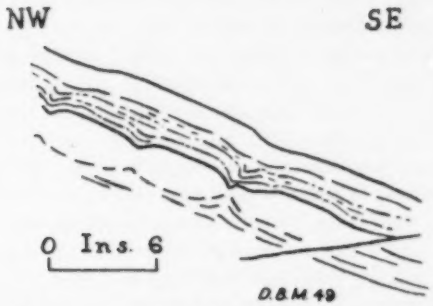
The occurrence of both boudinage and recumbent-folds at this locality reminds one of Wegmann's discussion (1932) of the association of these two structures : " In non-granitized terrains, recumbent-folds seem particularly favourable for the development of boudinage. They can evolve by *rolling* ; by the *push* of a resistant core which provokes backward-folding (encapuchonnement) ; or by *sliding on parallel surfaces*. These diverse types of movement may be combined " (p. 484, translated). Boudinage may be associated with any of these movements.

At this locality lineation takes several forms ; these include (i) the trace, on longitudinal sections, of points of inflexion (due to boudins or to folds) in the profile, (ii) minute folds and puckers parallel to the principal folds, (iii) preferred orientation of the long axes of crystals, and (iv) cleavage-bedding intersections. In all cases these are mutually parallel.

For geometric analysis of the structure any of these lineations may

be used. The visible folds maintain constant profiles for distances measuring many times their amplitudes. Provided that the major structures show a corresponding continuity in the axial-direction, the profile can be constructed from the map. Unfortunately, in this area it has not proved possible to differentiate any mappable zones, and therefore there is no data to project. For *geometric* analysis it is of no consequence whether the lineations described above are parallel to *a* or to *b*.

Kinematic analysis is difficult and tentative when the grand-scale structures are unknown, and in this region the absence of mappable zones leaves us in ignorance of structures on that scale. However, kinematic analysis is possible on a small-scale when structures such as those illustrated can be determined. The question which must be asked is " can this profile be explained by movement parallel to or per-



TEXT-FIG. 3.—Detail of boudinage from Text-fig. 1.

pendicular to the lineation-direction ? " It is obviously impossible to explain the structures illustrated, by the hypothesis that the lineation is in *a*. In the recumbent-fold shown in the text-figures, two points lying on a particular bedding-plane and once widely separated have moved towards one another ; one has then passed over the other ; and the points have then moved apart. This kinematic picture is inherent in the geometric form. It implies that the axis of rolling coincides more or less closely with the lineation-direction. Moreover, the structure of the boudinage is in accord with this movement picture.

It follows that the lineations described are *b*-lineations, similar to those described by the writer from Mid-Strathspey and Strathavon, to the north of the present area.

Attention has been drawn to this exposure because it indicates the type of data which must be accumulated before knowledge of either the geometry or the kinematics of this region can be acquired. Such

lineations must be systematically searched for and mapped, and the style and orientation of the observable structures must be carefully recorded. Not until this has been carried out will we be in a position to discuss the tectonics of the Struan Flags.

REFERENCES

BAILEY, E. B., 1925. Perthshire Tectonics: Loch Tummel, Blair Atholl, and Glen Shee. *Trans. Roy. Soc. Edinburgh*, liii, 671–698.

BARROW, G., 1904. On the Moine Gneisses of the East-Central Highlands and their Position in the Highland Sequence. *Quart. Journ. Geol. Soc.*, lx, 400–449.

GRANT WILSON, J. S., 1905. *In*, The Geology of the Country round Blair Atholl, Pitlochry, and Aberfeldy. *Geol. Surv. Scotland.*

MCINTYRE, D. B., 1950. Note on two lineated tectonites from Strathavon, Banffshire. *Geol. Mag.*, lxxxvii, 331–336.

WEGMANN, C. E., 1932. Note sur le Boudinage. *Bull. Soc. géol. de France*, 5e sér., ii, 477–491.

WILSON, GILBERT, 1946. The Relationship of Slaty Cleavage and Kindred Structures to Tectonics. *Proc. Geol. Assoc.*, lvii, 263–302.

Porosity of Wind-Deposited Sands

By J. KOLBUSZEWSKI, L. NADOLSKI, and Z. DYDACKI
Polish University College, London

ABSTRACT

To investigate the problem of porosity of wind deposited sands a sample of sand similar to Libyan Desert sand was used for wind tunnel experiments. Average velocity of wind—Average Porosity Curve was obtained for the first time, proving that low wind velocity produces higher porosity than high wind velocity, and that the relationship obtained agrees with the laws governing "vertical" deposition of sands.

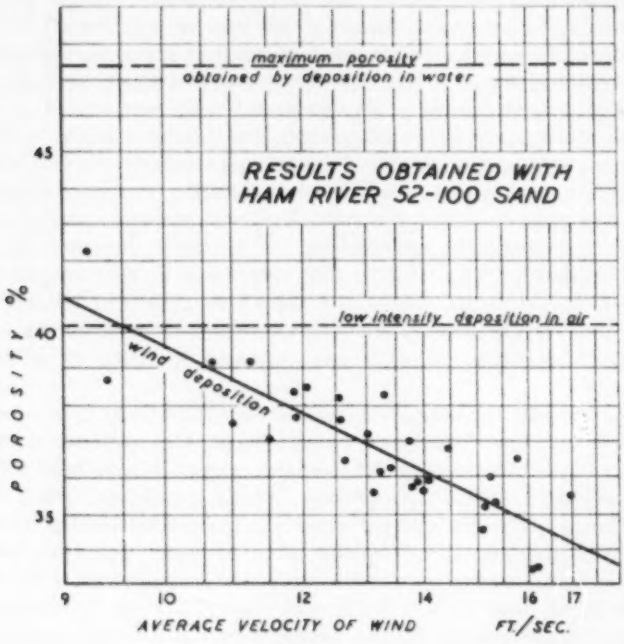
THE transport of solid particles of any kind by fluids in general is a matter of common interest. The subject is still very imperfectly understood and efforts are being made by various branches of science to deal with the problem. In the case of the natural movement of sand over the dry land of the earth and the effects of wind on dry sand in the desert sand storms, ripples, dunes have been described by geomorphologists. Recently the process of wind action on sand was investigated by Bagnold (1941), and the problem was explained from the point of view of aerodynamics. As far as the authors are aware the mechanics of the process with respect to the density of the wind-blown deposits have not been previously described. To provide an answer to this important question of density the research on packing and density of wind-deposited sands was started in the authors' laboratory, where a wind tunnel has been built and deposition of sands studied and density of deposits measured for various wind conditions. The research procedure had to fulfil a number of requirements in order to create all possible links with previous experimental work on deposition and packing of vertically deposited sands (Kolbuszewski, 1948, *a* and *b*). The influence of grading, roundness, sphericity, and specific gravity of grains on the density of the deposit have also been studied. The results are related to those obtained in standard treatment of sands and expressed in terms of relative porosity.

The first step was to establish the average wind velocity and average porosity relation. To find a sand possessing physical properties similar to the Libyan Desert sand, the following properties have been taken into account : sphericity, roundness, specific gravity, and grain size distribution. Samples were examined microscopically, photographed, and grains measured. Minimum and maximum porosities were measured by means of apparatus described (Kolbuszewski, 1948, *a*). Ham River Sand 52–100 B.S.S. was selected for the experiments. Table 1 shows how the selected sample compares with the sample of Libyan Desert sand.

TABLE 1

Sand	Size	Uniform Coefficient	Sphericity	Roundness	Specific Gravity
Libyan Desert Sand . .	52/100	1·3	0·850	0·530	2·7
Ham River Sand.	52/100	1·4	0·785	0·365	2·7

The location of points on the porosity/velocity graph (Text-fig. 1) is sufficient to determine the trend of investigated relation. There is a tendency for the curve obtained to sink below the minimum porosity limit. Although this limit (minimum porosity) for the investigated sand has not yet been firmly established, the authors are inclined to believe that the relation obtained is undoubtedly correct at the lowest velocities of deposition considered, when it is certain that no segregation took place (there are in the Ham River sand two sorts of grains



TEXT-FIG. 1.

with higher and lower specific gravity, and at higher wind velocities segregation occurred). On the other hand, if a series of samples are taken in future from deposits all along the tunnel and their specific gravity determined confirming the increasing segregation with increasing velocity (and therefore increasing specific gravity) then the whole curve will swing upwards around its established point, i.e. somewhere at average velocity = 10 ft./sec.

Finally, the experiments lead to the following facts :—

(1) A low wind velocity as, for example, 9·5 ft./sec. which was the lowest practical velocity in the tunnel sufficient to start the deposition, leads to higher porosity, in this case 38·7 per cent, that is 9·6 per cent lower than the maximum porosity obtained by standard test (47·4 per cent). It will be useful to add that the porosity obtained by pouring the sand slowly into 2,000 c.c. glass cylinder inclined at 45° was 46·6 per cent, that is, 0·8 per cent less than in vertical deposition. This gives an indication that " horizontally " deposited sand will result in lower porosity.

(2) A high wind velocity, as, for example, 16·25 ft./sec., almost the highest practical velocity in the tunnel, leads to low porosity—in our case the porosity obtained was 33·5 per cent, which is 3·2 per cent lower than the porosity obtained by vibrations of a sample under water (36·7 per cent). It should be mentioned that the value obtained by the vibrations under water seems to be very high, although the test was carried out according to the known procedure and repeated several times. It is quite possible that the deposit formed by the high velocity wind could be denser than that obtained by the vibrations. The " high velocity " deposition of dense deposits is due to the particular manner in which the individual grains are fitted into their final resting places.

(3) Indications were obtained that the intensity of deposition, the intensity of supply (called also rate of discharge), humidity of the air and temperature also influence the porosity of the deposit. These will be described in the future.

The authors' thanks are due to Professor A. J. S. Pippard, D.Sc., Brigadier R. A. Bagnold, F.R.S., Dr. A. W. Skempton, Dr. F. G. H. Blyth, and Mr. A. W. Bishop for their interest and advice.

REFERENCES

BAGNOLD, R. A., 1941. *The Physics of Blown Sand and Desert Dunes*, London.

KOLBUSZEWSKI, J., 1948A. An Experimental Study of the Maximum and Minimum Porosities of Sands. *Proc. Int. Conf. Soil Mech. and Found. Eng.*, vol. i, ii b, i. Rotterdam.

—— 1948B. General Investigation of Factors Controlling Loose Packing of Sands, *Proc. Int. Conf. Soil Mech. and Found. Eng.*, vol. vii, ii b. Rotterdam.

The Genus *Gigantella* Sarycheva

By J. E. Prentice

Abstract

The generic name *Gigantoproductus* nom. nov. is proposed to replace *Gigantella* Sarycheva, pre-occupied. The status of *Kansuella* Chao is discussed, and it is suggested that this be retained for the *kansuensis* group only.

THE genus *Gigantella* was proposed by Sarycheva (1928) for that clearly defined group of brachiopods, the giganteid Productidae, centred round the British form *Productus giganteus* (Martin). It has been brought to my notice recently that this generic name is pre-occupied by a crustacean (Ekman, 1905), a fact noted in a footnote to a paper on some members of this group (Prentice, 1949). Since 1928 the name *Gigantella* has been continually applied, by many authors, to the *Productus giganteus* group, and it is with regret that the author is forced to make a change in such a well-established name. The problems of nomenclature are complicated by the introduction, by Chao (1928), of the genus *Kansuella*, for an aberrant member of the *giganteus* group ; his imprecise definition of this and other related genera have added to the confusion. The present author's researches in the group have convinced him of its essential unity ; and an attempt is now made to rationalize some of the complexities of the nomenclature.

It has long been realized that the *giganteus* group of the Productidae was sufficiently different to allow of its separation. H. M. Muir-Wood (1928, p. 35), whilst including the group in the genus *Productus*, comments upon its distinctness. In the same year Sarycheva proposed the genus *Gigantella*, to include, amongst others, the familiar forms *P. giganteus* (Martin), *P. latissimus* J. Sowerby, *P. maximus* McCoy, and *P. edelburgensis* Phillips. Whilst Sarycheva does not expressly name *P. giganteus* as genotype, it is clear from the generic name that this was intended, and this has been formalized subsequently by H. M. Muir-Wood (1930) and W. Paeckelmann (1931). The latter author also furnished a formal diagnosis of the genus, based upon Sarycheva's description ; and had the name *Gigantella* not been preoccupied, it is clear that the genus would have been in every way satisfactory.

The invalidity of the name, however, brings in another factor ; slightly later in the same year Y. T. Chao (1928) published the second part of his monograph on the Chinese Productidae, in which he proposed some new generic names bearing upon the present study. In the first part (1927, p. 94) he had suggested the name *Striatifera* for the subgeneric group of Fischer's Striati. Within this subgenus he

recognized three sections—(1) *P. striatus* group, (2) *P. giganteus* group, and (3) *P. undatus* group—uniting them on the basis of their thin visceral cavity. He recognized the great variability of *Striatifera* and maintained that none of the characters was of a sufficiently permanent nature to allow of generic distinction. At the same time, he proposed the subgenus *Linoproductus* for the group of *P. cora* d'Orbigny. In his later part (1928) he reversed this opinion, stating that " the irregular *Stratifera* . . . marks only a peculiar sub-section of *Linoproductus* " ; he also specifically excluded the *giganteus* series by remarking that it is " widely distinct . . . probably not a true member of the *Productus* series ". There seems therefore to be no objection to regarding *Striatifera* Chao as a sub-section of the *Linoproductus* group, despite his original remarks. Chao then proceeded (1928, p. 67) to unite the *giganteus* series with a peculiar flattened form, *P. kansuensis*, which he made the genotype of a new genus *Kansuella*. Unfortunately, he states quite clearly in his diagnosis of this genus that he includes in it the *giganteus* series, though he recognizes points of distinction. His main point is that whereas *Kansuella kansuensis* invariably possesses an area in both valves, in the *giganteus* series the area is present " frequently " on the pedicle valve only. By studying the figures given by Chao, the present author has no doubt as to the similarity, in musculature and other internal structures, of *kansuensis* with the rest of the *giganteus* series. Moreover, the cardinal area is so variable even within the confines of a species in quite typical members of the *giganteus* series that its presence or absence on either valve has no validity for generic distinction. There seems no escape from the conclusion that *kansuensis* and the *giganteus* series are allied ; but the presence of a delthyrium and deltidium in *Kansuella* clearly distinguish it from the rest of the group. It would be inappropriate for such a homogeneous group to be defined by its most aberrant member ; and it is suggested that the name *Kansuella* be retained for the *kansuensis* series only, and that a new name *Gigantoproductus* be applied to the more normal members of the *giganteus* series.

The following constitutes the formal proposition of the new genus. The diagnosis follows closely that given by Paeckelmann (1931, p. 33), except for minor emendments, for the genus *Gigantella* Sarycheva.

Genus *Gigantoproductus* nom. nov. for *Gigantella* Sarycheva 1928.

Genotype : *Anomites giganteus* Martin (*Petrificata derbiensis* I, Tab. 15, 1809).

Diagnosis.—Moderate to very large, greatest width usually along the hinge line. Ventral valve strongly inflated, dorsal valve externally concave. Shell moderately to very thick, strongly ornamented by irregular radiating striae. Trail sometimes with irregular, radial folds. Concentric growth-wrinkles mainly confined to region of ears ; occasional

irregularly scattered spine bases. Cardinal process short and broad, two- or four-lobed. Median septum of dorsal valve broad posteriorly, high and narrow anteriorly. Brachial processes anterior to centre of adductor muscle-impressions, brachial ridges spreading, elongate and crescentic, partially enclosing the prominent brachial cones. In ventral valve deeply striate muscle impressions on either side of median pseudoseptum, which passes anteriorly into a median hollow ; hollows for reception of brachial cones deep or shallow. Cardinal area often present on ventral valve, rarely on dorsal.

REFERENCES

CHAO, Y. T., 1927. Productidae of China—Pt. I. *Pal. Sinica*, v, fasc. 2.
—— 1928. *Ibid.*, Pt. II, v, fasc. 3.
MUIR-WOOD, H. M., 1928. The British Carboniferous Productidae—II. *Mem. Geol. Surv. Palaeont.*, iii, pt. i.
—— 1930. The classification of the British Carboniferous Brachiopod Family Productinae. *Ann. Mag. Nat. Hist.* (10), v, 100–108.
PAECKELMANN, W., 1931. Die Brachiopoden des deutschen Unterkarbon 2 Teil ; Die Productinae und Productus-ähnlichen Chonetinae. *Abh. Preuss. Geol. Landesaust.*, N.F. Heft 122.
PRENTICE, J. E., 1949. The Hemisphaericus-like Gigantellids of the Southern Pennines. *Proc. Yorks. Geol. Soc.*, xxvii, pt. iv, 247–269.
SARYCHEVA, T. G., 1928. The Productinae of the group *Prod. giganteus* Mart. from the Viséan of Moscow. *Geol. Sci. Res. Inst. Mem. Moscow.*

CORRESPONDENCE

CARBONIFEROUS REEF LIMESTONES

SIR,—In his paper " The nomenclature of Lower Carboniferous ' Reef ' Limestones in the North of England " (*Geol. Mag.*, lxxxvii, 1950, 267), Dr. Bond implies (p. 269) that the limestone knolls at Grassington recently described by me (*Proc. Yorks. Geol. Soc.*, xxviii, 1950) are " true reef-knolls " as visualized by Tiddeman, and are similar to the diagram of a " true reef-knoll " shown in fig. 1 (p. 269) of his paper. This is only partly true. Firstly, the Grassington knolls consist of a core of partly recrystallized calcite mudstone, which may be bedded in its outer part but is usually unbedded or poorly bedded throughout, overlain by thinly-bedded crinoidal limestones which are bedded over and around the core. It is necessary, therefore, to distinguish between the core or knoll and the immediately overlying beds. The latter show original dips of deposition but they are no more " reef " limestones than are the hundred or so feet of evenly bedded limestones of the same highly crinoidal lithology which lie above them. Secondly, none of the Grassington knolls is a " discrete accumulation of organic debris " (Bond, op. cit., p. 269). Macrofossils are few and are mainly dwarfed brachiopods. Thin sections show abundant bryozoans, but these make up only a small proportion of the rock, which is largely calcite mudstone, partly recrystallized. The Grassington knolls do correspond to reef-knolls *as envisaged* by Tiddeman, in that they originated as mounds on the sea-floor. If they are to be called " reef-knolls " that term must be redefined so as to exclude organic debris as an essential major constituent. I would strongly support such a redefinition.

It is interesting to note that the lithology of these Grassington knolls is very similar to that found in the Bowland knolls—an unbedded or poorly bedded calcite mudstone which may be extensively recrystallized. Other types

of limestone may occur in addition, but the calcite mudstone seems to be an invariable constituent and the original knoll topography is moulded in it. This rock is one of the rare autochthonous limestones in a succession which is essentially allochthonous. It apparently accumulated in a quiet environment as a chemical or biochemical precipitate which retained its original and irregular mound-covered surface because of the absence of currents which elsewhere were sorting and distributing the constituents of the clastic limestones. That this surface was often extremely complex can be and has been demonstrated by Dr. Parkinson in the Clitheroe and Whitewell districts of Bowland. I find it very difficult to see in what way these limestones are different from the " unbedded reef-limestone ", discussed by Dr. Bond, the " main body " of which is " invariably pale-coloured unfossiliferous calcite mudstone " (Bond, op. cit., p. 274). Also, since he agrees that the Grassington and Bowland knolls are knolls of original deposition I do not understand his difficulty in seeing " how the unbedded reef limestone (of Cracoe) could have accumulated as distinct mounds " (Bond, op. cit., p. 277). The same rock type is concerned in all three cases. Is it not possible that there are original knolls at Cracoe and that some of the dips in the limestones are in part depositional and in part tectonic in origin ?

I would also venture to suggest that there may be difficulty in establishing an original knoll form where the covering rock is also a limestone and behaves similarly under erosion. Thus, at Scaleber and Malham it seems to be necessary to distinguish between knolls of three distinct ages. Firstly, the original knoll topography of the calcite mudstones which was quickly covered by limestones of D_1 and D_2 age ; secondly, the erosional knolls which were formed when these limestones were cut into by Pre-Namurian erosion and which, as Dr. Hudson has stated on numerous occasions, have no affinity with " reef-knolls ". Nevertheless, they often contain one or more of the original knolls. Thirdly, the erosional knolls of the present day which are being produced by the removal of the Bowland shale cover and by further erosion of the erosional knolls of the second age.

Finally, I would suggest caution in basing any reconstruction of conditions of deposition on the evidence of " tufa ". Work on which I have been engaged for some time suggests that some at least of this " tufa " is of secondary origin.

DEPARTMENT OF GEOLOGY,
THE UNIVERSITY,
NOTTINGHAM.
29th September, 1950.

W. W. BLACK.

NEW "SPECIES"

SIR,—The last paragraph of Mr. J. L. Begg's recent paper (1950) on Girvan trilobites contains a remarkable acknowledgment " . . . to Dr. A. E. Trueman for the suggestion that, meantime, this example [of *Teratorhynchus* sp.] should not be given a specific determination ". The specimen in question is incomplete and poorly preserved. That Mr. Begg should have considered erecting a new species upon a study of this material is a matter of some interest to geologists, representing as it does a very common approach to descriptive palaeontology. Recent publications by Burma (1948), Jeletzky (1950), Simpson (1941), and Simpson and Roe (1939), have drawn attention to the need for a more conservative treatment of questions of specific differentiation and at the same time to various " blind-spots " in some palaeontological work.

The possibilities of variation between closely related individuals or groups of individuals in an animal population are well-known and limited in number, being due to the presence of :—

1. *Subspecies*, usually mutually exclusive geographically, but capable of intermingling and replacement. It is worth noting that lateral (geographic) range of some animals is much underestimated by many palaeontologists. To some extent this may be attributed to a regrettable

tendency towards isolationism or nationalism among workers in this field (Jeletzky, 1950).

2. *Varieties in time*, caused by the normal processes of selective change and serving as links between conventionally separable " species ".
3. *Variants* within populations (and hence included in both (1) and (2) above) due to natural dispersion relative to a mean, to the presence of all growth stages, and to pathological causes (Aitken and McKerrow, 1948 ; Kaufmann, 1933).
4. Sexual dimorphism and polymorphism within populations (included in 1–3 above).

When these factors are taken into account it becomes evident that any random sample taken from a population, particularly if the sample is a very small one, may show considerable variation from the mean for any particular characteristic or attribute. In view of the pioneer work carried out in this field by, for example, Carruthers, O. T. Jones, and Trueman and Weir, one would have expected British workers to have reached an advanced stage of consciousness of the problems involved, especially in view of the recent rapid development of statistical methods designed for zoological application. So far from this being the case, however, much palaeontological descriptive work seems still to be concerned more with the proliferation of generic and specific names than with any desire to get a clearer picture of past animal communities. The records in such cases are often entirely useless to other workers who are not able to examine the actual specimens and the matrices in which they are contained. In particular, the practice of erecting new specific names on the basis of single, often incomplete and badly preserved, specimens can only be defended when applied to cases where early growth stages are retained in the " mature " individual or are derivable from the individual (as, for example, in graptolites, corals, and to a lesser extent brachiopods), and thus approximate the characters of a larger sample of the actual population.

In general (assuming that one of the objects of palaeontology is to assist in the development of a palaeoecological appreciation in its broadest sense) all descriptions should be based on samples capable of expression as better or worse approximations to the real formerly existing animal population. The *degree* of approximation can easily be recorded mathematically and gives an estimate *within exact limits* of the amount and directions of variability shown by members of a population, or the proportions within a population characterized by the presence or absence of certain attributes. Work along such lines will naturally tend to diminish the importance of the holotype in taxonomy and to substitute for it the group of syntypes—the " hypodigm " of Simpson. (It is, however, not at all the same thing to assemble such a group and merely to record a series of observed ranges for selected variates, since the observed range by itself is meaningless unless supplemented by estimates of dispersion, variability, etc.)

Finally, in addition to an estimation of the true population-characters the palaeontologist must always be considering the effect of environmental control in determining faunal assemblages and associations. How rarely is any indication given, in the general run of palaeontological work, of the mode of occurrence of the fossils, their relative abundance and relations with the prevailing sedimentary regime, their distribution in position of growth or as random assemblages. Yet all these are factors which are usually determinable without much difficulty and would serve as invaluable raw data for workers in similar and other closely related fields, such as palaeoecology and palaeogeography, especially where these are at the stage of synthesis. It is very desirable, if palaeozoological investigations are not to be progressively buried beneath the weight of their own accumulating nomenclature, that some sort of uniformity of treatment should be recognized at least as an ideal. The most valuable elements in such a scheme would be an increasing use of population-samples as the basis for specific identification rather than the rigid adherence

to the holotype concept, and a more general agreement and standardization in the use of the infraspecific units—subspecies, variety, and variant.

SEDGWICK MUSEUM, T. G. MILLER.
CAMBRIDGE.
September, 1950.

REFERENCES

AITKEN, W. G., and MCKERROW, W. S., 1948. Rhynchonellids of the Boueti Bed of the Great Oolite Series of Langton Herring, in Dorset : A Study in Variation. *Geol. Mag.*, lxxxv, 19–32.

BEGG, J. L., 1950. New Trilobites from Girvan. *Geol. Mag.*, lxxxvii, 285–291.

BURMA, B. H., 1948. Studies in Quantitative Palaeontology : I. *Journ. Pal.*, 22, 725–761.

JELETZKY, J. A., 1950. Some nomenclatorial and taxonomic problems in palaeozoology. *Journ. Pal.*, 24, 19–38.

KAUFMANN, R., 1933. Variationstatistische Untersuchungen über die " Artabwandlung " und " Artumbildung " an der Oberkambrischen Trilobitengattung *Olenus* Dalman. *Abhandlung aus dem geologisch-paläontologischen Institut der Universität Greifswald*, x, 1–54.

SIMPSON, G. G., 1941. Range as a zoological character. *Amer. Jour. Sci.*, 239, 785–804.

—— and ROE, A., 1939. *Quantitative Zoology*. McGraw-Hill.

SUPPOSED FOSSIL FROM THE CHARNIAN

SIR,—In the course of a study of the Pre-Cambrian rocks of Leicestershire a tubular object, resembling the kind of tube made by burrowing worms, was discovered in the Brand Series of Swithland Wood, Charnwood Forest, near the " Brand " on the east side of the Charnian dome.

The rocks of Swithland Wood and the near-by grounds of the " Brand " are made up of the so-called Brand ash and conglomerate. Quartzite is extremely abundant, interbedded with chloritic and slaty material ; the specimen was found in the interbedded slaty material.

The object is approximately 18 mm. long, about 2 mm. wide, tubular, the substance of the central space of the tube being composed essentially of vugh-like crystalline quartz. The tube shows nodular thickening or transverse ridges on its upper surface, the ridges about 3 mm. apart. The material composing the object is chlorite.

Lapworth (Watts, 1947, p. 104) [1] noted the lithological resemblance of the Cardingmill Grit, a member of the Synalds Group of the Stretton Series of the Longmynd, to the lower part of the Brand Series. So-called worm tracks and burrows have been reported from the Synalds Group in the Longmynd and Lapworth (Watts, op. cit., p. 104) also found a worm burrow in Bradgate Park, Charnwood Forest, about 1 to 1½ miles south of the " Brand ". From the same locality other specimens have since been reported by Bennett and Rhodes (Watts, op. cit., p. 104).

Nevertheless, some of the supposed markings found in the Pre-Cambrian, such as the so-called ripple-marks of the Longmyndian have lately been considered secondary deformation or related phenomena, and the " ripple-marks " have been termed shear and pressure effects. Similarly the so-called worm boring discussed here may have been of inorganic origin, and the external ridging of the tube may be of a fortuitous nature.

The specimen has been given to the Geological Survey Museum and is registered 84592.

GERALD M. FRIEDMAN.

UNIVERSITY OF CINCINNATI,
CINCINNATI 21.
OHIO.
20th October, 1950.

[1] WATTS, W. W., 1947. *Geology of the Ancient Rocks of Charnwood Forest, Leicestershire*. Leicester Literary and Philosophical Society.

ZOOLOGICAL NOMENCLATURE : ARTICLE 25

SIR,—The object of the present note is to elicit the views of zoologists on the question whether it is desirable to maintain or to modify the provision in the *Règles* that a trivial name published in a specific synonymy thereby acquires rights under the Law of Priority as an objective synonym of the name of the nominal species in the synonymy of which it was so published and accordingly (*a*) is available to become the valid name of the species in question if later it is found that the earlier name in the synonymy of which it was published is invalid as a junior homonym of some other name consisting of the same word, and (*b*) renders invalid as a junior homonym any later different use of the same specific trivial name in combination with the same generic name.

The reason why this question is brought forward at the present time. As Secretary to the International Commission on Zoological Nomenclature, I have received a letter from a distinguished specialist in vertebrate zoology, urging that the Commission should recommend the Congress to reverse the present rule, on the ground that in his particular speciality the application of that rule leads in certain cases to the result (1) that a trivial name bestowed in manuscript upon a particular specimen but later published by the author concerned for the species represented by that specimen is not available for that species, because in the meantime the manuscript name in question has been erroneously published in the synonymy of some other species, and (2) that, as such publication in a synonymy has been ignored by later authors, confusion would result from the application of the present rule, which he accordingly recommends should be repealed. In the absence of information as to what is the general practice of specialists in relation to the ruling given in *Opinion 4*, it is not possible to form any considered opinion on the question whether particular cases of the kind described above could best be dealt with, and confusion prevented, by the Commission's use of its plenary powers, or whether, on the other hand, the better course would be to secure the approval of the Congress for the repeal of this provision in Article 25. If that course were followed, some use of the plenary powers would, no doubt, also be required to provide a valid standing for trivial names published in specific synonymies and since brought into general use (through the name with which the unpublished name was synonymized, having been found to be an invalid homonym), since, if that were not done, unnecessary confusion and name-changing would result from the proposed amendment of Article 25 although that amendment had, as its express object, the prevention of confusion and unnecessary name-changing as the result of the strict application of the *Règles*.

The origin and present status of the existing rule. The rule that a trivial name published in a specific synonymy acquires availability under both the Law of Priority and the Law of Homonymy in virtue of being so published was first promulgated in 1907 when the Seventh International Congress of Zoology at its meeting held in Boston, Massachussetts, approved *Opinion 4* rendered shortly before (but not until then published) by the International Commission on Zoological Nomenclature. This provision has therefore been part of the international system of zoological nomenclature for over forty years. When in 1948 the Thirteenth International Congress of Zoology incorporated into the *Règles* the rulings in regard to the *Règles* given in *Opinions* previously rendered by the International Commission, it so incorporated the provision now under consideration (1950, *Bull. zool. Nomencl.*, 4, 145–6). This provision will accordingly appear in the text of the *Règles* as amended by the Paris Congress, when that text is published.

The validity of the ruling given in "Opinion" 4 not a relevant issue. The ruling in *Opinion 4* that a trivial name published in a specific synonymy thereby acquired rights under the Law of Priority has occasionally been criticized on the ground that it was inconsistent with the general provisions of Article 25 and was therefore *ultra vires* and invalid. But once *Opinion 4*

had been approved by the Congress (as it was in 1907), the possibility of its being *ultra vires* was no more open to question than that of any Article in the *Règles*. This position was reaffirmed by the express decision of the Paris Congress to include it in the revised text of the *Règles*.

The only issue which remains to be considered is therefore whether the provision in question is in harmony with the general needs of zoologists and palaeozoologists, and, if not, in what direction it is desirable that the International Commission on Zoological Nomenclature should recommend the Fourteenth International Congress of Zoology to amend this provision at its meeting to be held in Copenhagen in 1953.

The present issue in relation to stability in zoological nomenclature. As already noted, the provision with which we are here concerned has formed part of the international system of zoological nomenclature for over forty years. What the Commission needs first to ascertain is what is the general practice of specialists working in each of the various groups of the Animal Kingdom, for clearly the question whether the ruling given in 1907 that a trivial name published in a specific synonymy is to be accepted as possessing rights under the Law of Priority has since been generally accepted or alternatively has been widely overlooked or disregarded is of cardinal importance in any consideration of this question, having regard to the overriding need of avoiding any action which might give rise to instability in zoological nomenclature.

Scope of the present inquiry. In the actual case brought to the attention of the Commission which has given rise to the present inquiry, the problem raised was in relation only to the status of a trivial name bestowed on a specimen in manuscript when the first occasion on which that name is published is in a specific synonymy. It would clearly not be possible to limit any change of the *Règles* to this restricted class of name, for manuscript names have in the past often been published in this way without any indication on the part of the author by whom they were published, whether he was aware that the name in question was still an unpublished manuscript name or whether he believed that that name had already been validly published either by the author by whom the name had been originally proposed in manuscript or by some other author. Any new provision (like the existing provision) would therefore need to apply to all trivial names, when first published in specific synonymies, for it would be wrong in principle and unworkable in practice to devise a provision, the application of which called for a subjective decision on the part of the reviser as to whether an author who published a manuscript name in a specific synonymy was or was not aware that the name which he so published was or was not an unpublished manuscript name previously proposed by some other author. Moreover, a change limited in the foregoing manner, even if that were practicable, would not meet the point which has been raised, for it has often happened that the first time that a manuscript name has appeared in print it has done so as a *nomen nudum* and that it was only when it was next published that it appeared in a specific synonymy. It seems evident therefore that, if any change were to be made in the present rule, it would need to apply to all trivial names first published in specific synonymies ; it would therefore have to cover (*a*) any name originally proposed in manuscript which, when first published, was published in a specific synonymy by the author by whom it had originally been proposed in manuscript ; (*b*) any name published conditionally as a possibly needed *nomen novum* (substitute name) or as an emendation of the trivial name with which it is synonymized.

Need for avoidence of name-changing while the present question is under consideration. In this, as in other cases of a similar kind, it is important that there should be no disturbance in existing nomenclatorial practice while the question of principle involved is under consideration, for premature name-changing of this kind would run counter to the expressed desire of the Congress that all unnecessary name-changing should be avoided.

Questions on which it is desired that specialists should furnish information.

In the light of the foregoing considerations specialists are urged to furnish the Commission with answers to the following questions :—

(1) Do you in your work accept as an available name (that is, as a name possessing rights under the Law of Priority and the Law of Homonymy) a trivial name originally published in a specific synonymy ?

(2) Do other specialists in your field treat such a trivial name in the same way that you do ?

(3) In what branch of the Animal Kingdom are you a specialist ?
Note.—Please answer this question as precisely as possible and indicate also whether you work on living forms or on fossils.

(4) (*To be answered only by those specialists whose answer to Question No.* (*1*) *is* "*yes*"). Do you consider that confusion and name-changing would result in your special field if the *Règles* were altered in such a way as to render unavailable a trivial name published in a specific synonymy ?

(5) (*To be answered only by those specialists whose answer to Question No.* (*1*) *is* "*no*"). Do you consider that confusion and name-changing would result if the present rule that a trivial name published in a specific synonymy thereby acquires availability were to be strictly applied to specific names in your special field ?

Return of replies to the foregoing questions. It is particularly hoped that as many zoologists and palaeozoologists as possible will furnish replies to the foregoing questions ; further, it is hoped that specialists will be good enough, when answering Question No. (4) or, as the case may be, Question No. (5), to cite definite examples of cases where they apprehend that confusion would arise in the circumstances there stated. All replies to the foregoing questions should be addressed to me clearly marked "Z.N. (S.) 372".

FRANCIS HEMMING.
Secretary, International Commission on Zoological Nomenclature.

28 PARK VILLAGE EAST,
REGENT'S PARK,
LONDON, N.W. 1.
October, 1950.

DEPTH OF BURIAL OF SOUTH WALES COALS

SIR,—Mr. Wellman's interesting contribution on the depth of burial of South Wales coals falls into two parts. First he deals with the formula for calculating coal seam volatiles at depth, and this is independent of the second and more speculative part in which he propounds a new variation of the depth of burial hypothesis to explain the devolatilization of these seams.

Workers on devolatilization formulae would be well advised to heed Wellman's statement that "for practical purposes in order to calculate the rank of coal at depth, it is convenient to use a single gradient for the whole of the coalfield". Wellman considers that Trotter's original square-root equation fits the analyses reasonably well, but advances his own logarithmic formula as giving slightly more accurate results. At the time his paper went to press he was apparently unaware of the exponential equation for South Wales coals (Trotter, *Geol. Mag.*, 1950, p. 196) which is a blood relation of his formula.

In the speculative part of his paper, Wellman has postulated two devolatilizations for South Wales coals, (*a*) a devolatilization on the South Crop of the coalfield which is considered to be due to burial by the admittedly thick Coal Measures sediments of that area and (*b*) a second and later devolatilization thought to be due to burial by post-Carboniferous sediments which are considered to thicken northwards so as to reach a thickness of about 15,000 feet, giving an overall thickness of about 18,000 feet over the northern fringe of the anthracite field. The combined effect of both devolatilizations

is portrayed in an illustration that is founded on a horizontal section across the coalfield published by Trotter (*Quart. Journ. Geol. Soc.*, civ, p. 396).

In Wellman's illustration high rank coals of 16 per cent or less volatiles are shown, in the basal Coal Measures, to crop out in the extreme south in a position which is beneath the sea, from where there are no analyses available. But these lowest seams of the South Crop are beneath the sea only along a limited distance; for the most part they outcrop on land, across Gower, where they are bituminous coals of 28–30 per cent volatiles.

It is incontestable, on the basis of the theory that devolatilization is due to depth of burial, that high rank coals should have occurred in the basal Coal Measures of the South Crop. The fact that relatively low rank coals occur instead forces us to abandon the theory, at least in its application to the seams of the South Crop.

As regards the suggested later devolatilization such a thickness of post-Carboniferous sediments as is demanded over the anthracites to account for these very high rank coals appears to be highly improbable when one considers that the nearest Permo-Trias is represented by a mere 100 feet or so of uppermost Keuper. A thickness of post-Carboniferous sediments of 15,000 feet is, of course, acceptable for the Lancashire–Cheshire basin with the Permo-Trias alone accounting for a thickness of 8,000 to 10,000 feet, and here one may also have an additional 3,000 feet of Coal Measures above the lower coals. But the coals of South Lancashire, worked beneath the Permo-Trias down to a depth of 4,000 feet below O.D., are not anthracites; on the contrary they are bituminous coals with volatiles of 32–40 per cent. Under these circumstances one need not consider in detail whether the post Carboniferous rocks of South Wales thickened, or as seems more probable, thinned northwards against the St. George's Land of Central Wales. In either case their presence is not likely to have raised the seams to a rank higher than the bituminous coals of South Lancashire.

In one important respect, however, the rank of coal can be shown to rise with corresponding depth of cover. Wellman has shown with the aid of the Notown bore that a rise in rank from sub-bituminous to bituminous coal is due essentially to expulsion of moisture, bituminous rank being attained under an approximate cover of 8,000 feet. The writer (*Geol. Mag.*, 1950, pp. 201–2) goes further than this in stating that expulsion of water is the primary cause of rising rank with depth in all coalfields that have neither been subjected to strong compressional influences nor to the effects of vulcanicity.

F. M. Trotter.

250 Oxford Road,
Manchester, 13.
October, 1950.

REVIEWS

Das Klima der Vorzeit: Ein Einführung in die Paläoklimatologie. By Martin Schwarzbach. 8vo, pp. viii + 211, with 70 illustrations, Ferdinand Enke Verlag, Stuttgart, 1950. D.M. 19.00 (geb. 21.80).

Geologists will find this a compact and most useful introduction to a very big subject and, as Professor Schwarzbach occupies the chair of geology at the University of Cologne, his approach will be acceptable. For a great part of the evidence for past climates must be provided and sifted by geologists and the critical and cautious attitude with which the author assembles and reviews the evidence is to be commended. Following a brief but welcome summary of the historical development of the study of palaeoclimatology, a third of the book is devoted to the methods by which past climates can be reconstructed. The results with regard to the earth as a whole are then summarized for each of the geological periods. Finally, the author discusses the possible causes of climatic change, terrestrial and extra-terrestrial, which will remind British readers of the somewhat different approach by Dr. C. E. P.

Brooks (*Climate through the Ages*, 1949), and the more detailed arguments of Professor Zeuner in *Dating the Past* (1946).

It is, indeed, stimulating to read such a thorough survey in a field in which there is a tremendously scattered literature ; the author gives 850 references in his bibliography, which is thoroughly international in scope and includes all the older standard references. To these are added a large number of more recent German papers and, for example, several by the author published during the war years. Taking into account the author's scope and purpose, omissions appear to be few. British readers will find this compilation a useful guide, as German contributions in this field have always been noteworthy. One may note, for example, the table of recent estimates of the lowering of temperature in the Ice Age (p. 146). Diagrams and maps will catch the eye, e.g. the distribution of the Eo-Cambrian glaciation (p. 98). Readers will turn to the comments on the Permo-Carboniferous glaciation ; Professor Schwarzbach summarizes the Brooks-Umbgrove and Köppen-Wegener reconstructions, and while he qualifies Wegener he is critical of the " relief hypothesis ". Admitting the difficulties, he nevertheless finds it hard to avoid the conclusion that there has been land movement relative to the pole previous to the Tertiary, since when, however, it has played no part. From his own papers he illustrates (p. 158) the southward latitudinal movement of the reef-coral zone in the northern hemisphere between the Cambrian and the Cretaceous.

In all, a thoughtful and comprehensive introduction ; as a geologist, the author has relatively little to say about the post-glacial and historic periods, and it is perhaps for meteorologists to discuss the relationships between present and past climatic fluctuations within the framework of the geological and botanical evidence.

A minor but very attractive feature is the elegant and delightfully apposite series of quotations with which chapters are headed. Not only does the author quote as is proper from Goethe ; among others, including Lyell and Coleman, readers will much enjoy those from Lichtenberg and Cowper. Printing and production are admirable.

G. M.

APPLIED SEDIMENTATION : A Symposium. Edited by PARKER D. TRASK. John Wiley and Sons (London : Chapman and Hall), 1950. pp. xi + 707, with numerous figures. Price 40*s.* net.

It is significant of the high status of sedimentary studies in the United States that a volume has now appeared devoted to the application of those studies to fields usually delegated in Britain to economic geology or to civil engineering. *Applied Sedimentation*, prepared under the direction of the Committee on Sedimentation of the National Research Council, and edited by Parker D. Trask, includes thirty-five chapters, each written by one or more specialists and grouped into seven parts : Basic principles of sedimentation ; Engineering problems involving strength of sediments ; Applications of processes of sedimentation ; Applications involving nature of constituents ; Economic mineral deposits ; Petroleum geology problems ; Military applications.

The individual chapters vary from lucid factual summaries of prescribed fields of sedimentology, of which Trask's own contribution is outstanding in treatment and Black's " Permafrost " refreshingly new in scope, to generalized accounts of the application of the physical sciences to sedimentation. Each of the papers is well documented, and the almost inevitable overlap is small. We are told that a major aim of the book is to present material of common interest to the geologist and the engineer, so that they can co-operate more effectively in their work. The first part of this intention is fully achieved ; it remains only to use this volume as a standard textbook and reference work in the common ground between sedimentation and engineering.

J. E. H.

THE

GEOLOGICAL MAGAZINE

VOL. LXXXVII OF WHOLE SERIES

JANUARY–DECEMBER, 1950

GEOLOGICAL MAGAZINE

with which is incorporated

THE GEOLOGIST

FOUNDED IN 1864 BY THE LATE DR. HENRY WOODWARD, F.R.S.

Edited by

O. M. B. BULMAN, Ph.D. A.R.C.Sc., F.R.S.

and

S. R. NOCKOLDS, Ph.D.

assisted by

PROFESSOR W. S. BOULTON, D.Sc.
PROFESSOR W. G. FEARNSIDES, M.A., F.R.S.
PROFESSOR LEONARD HAWKES, D.Sc.
PROFESSOR O. T. JONES. M.A., D.Sc., F.R.S.
W. J. PUGH, O.B.E., D.Sc.
PROFESSOR C. E. TILLEY, Ph.D., F.R.S.
HENRY WOODS, M.A., F.R.S.

Vol. LXXXVII of Whole Series

JANUARY—DECEMBER, 1950

STEPHEN AUSTIN & SONS, LTD

1 FORE STREET, HERTFORD, HERTS

HERTFORD

STEPHEN AUSTIN AND SONS, LTD.

CONTENTS OF VOLUME LXXXVII, 1950

No. 1 JANUARY–FEBRUARY PAGE

B. F. HOWELL and C. J. STUBBLEFIELD. A Revision of the Fauna of the North Welsh *Conocoryphe viola* Beds implying a Lower Cambrian Age 1

H. WATSON. A Note on Bathonian Gastropods Assigned to Fresh-water Genera 17

W. SUGDEN. The Influence of Water Films adsorbed by Mineral Grains upon the Compaction of Natural Sediments and Notes on Allied Phenomena 26

G. WILSON. An Experimental Synthesis of Quartz, Albite, and Analcite 41

E. M. PATTERSON. Evidence of Fissure Eruption in the Tertiary Lava Plateau of North-East Ireland 45

F. E. EAMES. On the Age of the Fauna of the Bugti Bone Beds, Baluchistan 53

G. P. LEEDAL and G. P. L. WALKER. A Restudy of the Ingletonian Series of Yorkshire 57

CORRESPONDENCE.—Remarks on Dr. Lamont's Interpretation of Features in the Trilobite *Platycalymene*, 67 ; Hilt's Law and the Volatile Contents of Coal Seams, 68 ; The Lizard-Start Problem, 71.

REVIEWS.—Physical Geology, 71 ; A Student's Introduction to Geology Mainly Physical, 71 ; Karroo Dolerites of the Union of South Africa, 72.

No. 2 MARCH–APRIL

OBITUARY—R. H. Rastall, 1871–1950 73

L. F. SPATH. The Study of Ammonites in Thin, Median Sections . 77

R. W. CHAPMAN. Contact Metamorphism at Maddocks Hill near Wellington, Shropshire 85

R. PERRIN and M. ROUBAULT. Metamorphism of the Trias in the Alps 89

K. O. EMERY. A Suggested Origin of Continental Slopes and of Submarine Canyons 102

J. R. F. JOYCE. Stone Runs of the Falkland Islands. 105

M. R. W. JOHNSON. The Fauna of the Rhaetic Beds in South Nottinghamshire 116

M. S. SADASHIVAIAH. Olivine-bearing and other Basic Hornfelses around the Insch Igneous Mass, Aberdeenshire 121

E. GREENLY. The Tectonics of Holland Arms 131

C. D. WATERSTON. Note on the Sandstone Injections of Eathie Haven, Cromarty 133

CORRESPONDENCE.—Investigation of the Torridonian, 139 ; Kent's Cavern, Torquay, 139 ; Pre-Cambrian Formations of India, 140 ; Oceanic Meanderings, 144.

REVIEWS.—Introduction to College Geology, 146 ; Historical Geology 146 ; Outline of Historical Geology, 146 ; Geology for Engineers, 146 ; Probleme der Naturwissenschaften erläutert am Begriff der Mineralart, 147 ; Ore Genesis : A Metallurgical Interpretation, 147.

No. 3 MAY–JUNE

V. E. FUCHS. Pleistocene Events in the Baringo Basin, Kenya Colony 149

M. H. KHAN. Note on the Depth and Temperature of the Gault Sea as indicated by Foraminifera 175

W. A. DEER. The Diorites and Associated Rocks of the Glen Tilt Complex, Perthshire. II. Diorites and Appinites. 181

F. M. TROTTER. The Devolatilization Equation for South Wales Coals 196

J. A. ROBBIE. The Chalk Rock at Winterborne Abbas, Dorset . . 209

F. E. EAMES. The Position of the Laki Limestone in the Eocene Succession of Western Pakistan 214

J. N. JENNINGS. The Origin of the Fenland Meres : Fenland Homologues of the Norfolk Broads 217

CORRESPONDENCE.—Hilt's Law and the Volatile Contents of Coal Seams 225 ; *Coeloteuthis* and Synonymous Homonymy at Generic Level, 226 ; Pre-Cambrian Formations of India, 227 ; Bathonian *Viviparus*-like Gastropods, 228.

REVIEWS.—Principles of Structural Geology, 232 ; International Geological Congress Report, 232.

No. 4 JULY–AUGUST

F. E. EAMES. On the Ages of Certain Upper Tertiary Beds of Peninsular India and Ceylon 233

H. BARTENSTEIN. Micropalaeontological Research in European Upper Carboniferous Stratigraphy 253

C. J. STUBBLEFIELD and W. EDWARDS. Marine Bands in the Coal Measures of Britain and Germany 261

J. MYERS. Note on the Age of the Rocks on the East Side of Newport Bay, Pembrokeshire 263

W. J. ARKELL. Two Early-named Valid Species of English Upper Jurassic Ammonites 265

G. BOND. The Nomenclature of Lower Carboniferous "Reef" Limestones in the North of England 267

H. G. MIDGLEY. An Upper Eocene Outlier at St. Ann's Hill, Chertsey 279

J. L. BEGG. New Trilobites from Girvan 285

P. TASCH. Darwin and the forgotten Mr. Lonsdale 292

W. T. HARRY. Basement Carboniferous in Upper Teesdale, N. Yorks 297

CORRESPONDENCE.—Cephalic Segmentation and Sutures in Trilobites, 300 ; *Platyharpes* Whittington, 1950, a Synonym of *Hibbertia* Jones and Woodward, 1898, 302 ; Chalk Rock of Dorset—More Evidence of Salt ? 302 ; Synonymous Homonymy at Generic Level, 303.

REVIEWS.—Stratigraphy and Paleontology of the Brownsport Formation (Silurian) of Western Tennessee, 303 ; Petrography of the Island of Hawaii, 304 ; An Index of Mineral Species and Varieties arranged Chemically, 304 ; Volcanological Observations, 304 ; Die Erzmineralien und ihre verwachsungen, 304.

ANNOUNCEMENT.—International Committee for the Study of Clays, 262.

No. 5 SEPTEMBER–OCTOBER

H. H. WELLMAN. Depth of Burial of South Wales Coals . . . 305
R. W. FAIRBRIDGE. Pre-Cambrian Algal Limestone in Western Australia 324
D. B. MCINTYRE. Note on Two Lineated Tectonites from Strathavon, Banffshire 331
D. PARKINSON. Some Features of the Lower Carboniferous Reef Limestones of Clitheroe, Lancashire 337
O. M. B. BULMAN. Rejuvenation in a Rhabdosome of *Dictyonema flabelliforme* 351
L. KING. Speculations upon the Outline and the Mode of Disruption of Gondwanaland 353
C. A. COTTON. Axes of Active Warping in the New Zealand Seismic Region 360
B. C. KING. Some Large Felspar Augen from near Ilorin Town, Nigeria 369
V. A. EYLES. The First National Geological Survey 373
CORRESPONDENCE.—Floor of the English Channel, 383; Diorites and Appinites, 384.

No. 6 NOVEMBER–DECEMBER

S. W. TROMP. The Age and Origin of the Red Sea Graben. . . 385
W. K. SPENCER. Asterozoa and the Study of Palaeozoic Faunas . 393
W. A. MACFADYEN. Sandy Gypsum Crystals from Berbera, British Somaliland 409
G. M. PART. Occurrence of Nepheline-Monzonite and Allied Types in the Cape Verde Archipelago 421
D. B. MCINTYRE. Note on Lineation, Boudinage, and Recumbent folds in the Struan Flags (Moine), near Dalnacardoch, Perthshire 427
J. KOLBUSZEWSKI, L. NADOLSKI, and Z. DYDACKI. Porosity of Wind-Deposited Sands 433
J. E. PRENTICE. The Genus *Gigantella* Sarycheva 436
CORRESPONDENCE.—Carboniferous Reef Limestones, 438; New "Species", 439; Supposed Fossil from the Charnian, 441; Zoological Nomenclature: Article 25, 442; Depth of Burial of S. Wales Coals, 444.
REVIEWS.—Das Klima der Vorzeit: Ein Einführung in die Paläoklimatologie, 445; Applied Sedimentation, 446.
INDEX.—447.

Specimens Wanted . . . .

Will purchase or exchange Sponges and Echinoderms from the Cenomanian, pyritized specimens from the Gault, fossil fish from the Ludlow of Scotland, or any fauna from the Lias and Cambrian. Please itemize these or any other offerings, stating condition and price of each. Do not ship any materials without proper authorization and instructions from us.

WARD'S NATURAL SCIENCE ESTABLISHMENT, INC.
3000 RIDGE ROAD EAST, ROCHESTER 9, NEW YORK, U.S.A.

The Geological Magazine

Bound volumes are better than loose parts. Send your *Geological Magazine* to be bound in attractive green cloth covers, 9s. (postage 7d. extra); cloth cases only, 4s. (postage 3d. extra).

STEPHEN AUSTIN & SONS, LTD.
1 FORE STREET, HERTFORD

EDWARD ARNOLD & CO.

THE GEOLOGY OF THE COMMONWEALTH OF AUSTRALIA

By the late **Sir T. W. Edgeworth David**, K.B.E., F.R.S. Edited by **W. R. Browne**, D.Sc., Reader in Geology, University of Sydney. In Three Volumes. 1,400 pages, 85 plates, 372 maps and sections in black and white. **£12 12s.** net.

Coloured map of Australian New Guinea sold separately. **6s.** net. By post in a tube, **7s.** net.

CRYSTALS AND THE POLARISING MICROSCOPE

A Handbook for Chemists and Others. By **N. H. Hartshorne**, Ph.D., M.Sc., and **A. Stuart**, M.Sc., F.G.S. *Second Edition.* xii + 473 pages, 313 diagrams. **50s.** net.

An attempt to meet the needs of those whose researches call for a more advanced treatment, while still not discouraging the beginner.

OUTLINES OF PALÆONTOLOGY

By **H. H. Swinnerton**, D.Sc., F.G.S. *Third Edition.* xii + 393 pages, 368 diagrams. **32s. 6d.** net.

"This new edition of Professor Swinnerton's book will be much appreciated by geology students . . . and zoology students should also find this book helpful."—*Geological Magazine.*

41 MADDOX STREET, LONDON, W.1